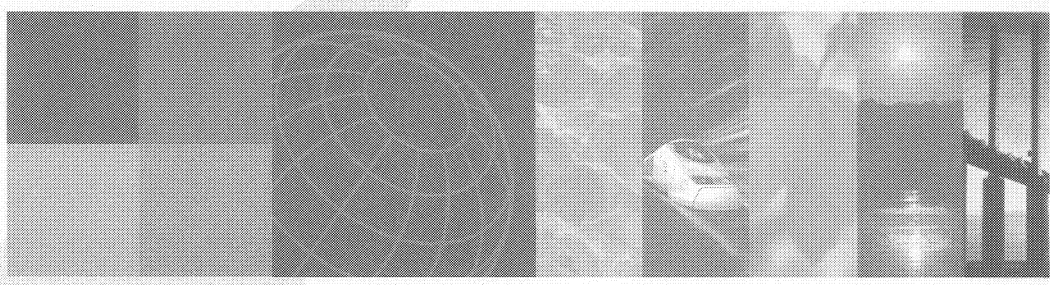
Scarborough Borough Council

Cayton Bay Coastal Strategy Study

Strategy Report (Final)

October 2002



Halcrow Group Limited

Halcrow

Scarborough Borough Council

Cayton Bay Coastal Strategy Study

Strategy Report (Final)

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Scarborough Borough Council

Cayton Bay Coastal Strategy Study
Strategy Report (Final)

Contents Amendment Record

This report has been issued and amended as follows:

Issue	Revision	Description	Date	Signed
1	0	Draft	July 2001	KMcC
2	0	Revised draft (previously in 3 volumes)	Sep 2001	KMcC
3	0	Final	Oct 2002	

Contents

Annexes (in separate volume)

A Bathymetric & Topographic Survey

B Summaries of Models Used

C Historic Cliff Recession Data

D Cliff Recession Database & Mapping

E Strategic Environmental Assessment

F Economic Assessment

1 Introduction

1.1 *Background & Scope of Study*

Halcrow were commissioned by Scarborough Borough Council to assist in producing a coastal strategy study for Cayton Bay. The study covers Coastal Process units 24A and 24B as defined in the Huntcliffe to Flamborough Head Shoreline Management Plan, Figure 1.1.

1.2 *Objectives of the Study*

The strategy study will:

- provide information on the condition and performance of existing defences;
- where appropriate, identify options to provide cost-effective and efficient coast protection for a strategy duration of 50 years;
- identify a preferred option for each discrete length of coastline;
- recommend a preferred programme of work;
- provide information that can be subsequently used in the design of future coast protection.

Key objectives of the strategy are:

- predictions of cliff recession rates on unprotected lengths of coastline;
- proposed intervention works, to provide appropriate levels of coastal protection for the next 50 years;
- an assessment of the sediment budget for Cayton Bay;
- preservation of property and safety of the public;
- elimination / reduction of landslip / cliff recession risk in defended areas;
- reduction in risk to coastal defences from coastal instability;
- identification and evaluation of assets at risk from coastal erosion.

Key activities that have been undertaken to inform the strategy development are:

- strategic environmental assessment
- detailed cliff mapping

- topographic and bathymetric survey

The cliff mapping study allowed quantification of cliff recession rates, identifying zones at risk within the strategy lifetime. This has helped prioritise intervention works and has been used to provide planning guidance for the coastal zone.

Throughout the development of the strategy, reference has been made to the Shoreline Management Plan

1.3 *Format of Reports*

Following this introduction, Chapter 2 describes the physical features of Cayton Bay, including geology, geomorphology, and features of the foreshore and seabed. Hydrodynamics within the Bay are presented in Chapter 3, including the results of wave modelling studies undertaken as part of the Study.

The detailed cliff assessment studies that were undertaken are presented in Chapter 4, including quantification of the sediment contribution into the Bay from the cliffs and mapping of cliff geomorphology and recession potential. Coastal processes within the Bay are discussed in Chapter 5, sediment transport modelling that was undertaken, and an assessment of the sediment budget. The existing defences along the frontage are identified and described in Chapter 6, where an assessment of their condition is made and key issues noted. The Strategic Environmental Assessment process is summarised in Chapter 7, Environmental Objectives are identified and the implications of the 'do nothing' scenario are discussed. The full Strategic Environmental Assessment is provided in Annex D.

Chapter 8 discusses the approach to assessing alternative strategic options for the Bay, with each management unit being considered in more detail in Chapter 9. Reference is made in Chapter 9 to the environmental and economic assessment of the strategic options, which are presented in more detail in Annexes E and F.

Recommendations and conclusions are given in Chapter 10, together with a summary comparison with the Shoreline Management Plan and identification of key differences in recommended policy where appropriate. An Implementation Plan is given in Chapter 11.

1.4 *Previous Studies*

Studies were previously undertaken for the area as part of the Huntcliffe to Flamborough Head (Sub-cell 1d) Shoreline Management Plan, completed in 1997.

This is a key document that outlines recommended shoreline management policies for each of the management units within the study area. These recommended policies are reviewed and developed further as part of this strategy.

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CAYTON BAY COASTAL STRATEGY STUDY

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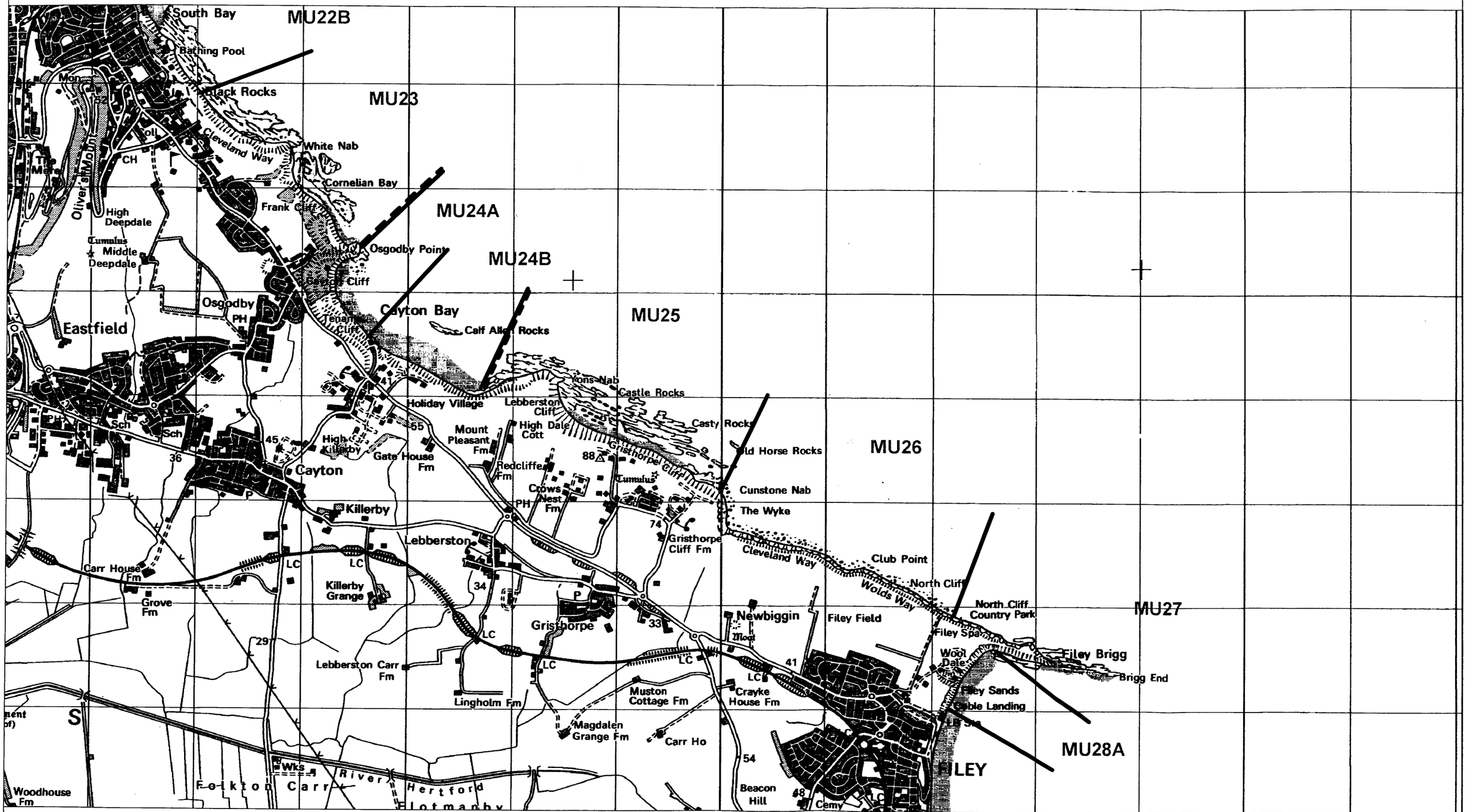

2 Physical Environment

2.1 *Setting*

Cayton Bay is located on the north-east coast of England. Its limits are defined by Knipe Point to the north and Yon's Nab to the south (Figure 1.1). The Bay comprises Jurassic sedimentary rocks overlain by glacial till. A series of faults run through the Bay. These have resulted in a range of lithologies being exposed within the Bay, which influencing the development of the coastline. Aerial photographs showing the extent of the Bay are included in Figure 2.1.

2.2 *Geology and Geomorphology*

2.2.1 *General*

The geology of the study area comprises sedimentary rocks of Jurassic age overlain by variable thicknesses of glacial till. The area is structurally complex, with a series of faults generally running N – S and NNE – SSW through Cayton Bay. The pattern of faulting has resulted in a range of lithologies exposed in the cliffs which control the spatial and temporal development of the coastline and the scale of landsliding.

Cayton Bay can be divided into two main landforms with regard to the nature and scale of coastal landsliding. Two pre-existing large-scale, deep-seated landslides are present in the northern part of the bay where the Lower Calcareous Grits overly the Oxford Clay. The landslide complexes are found at Tenants Cliff and Cayton Cliff and were probably formed by marine erosion of the underlying incompetent clays and failure of the overlying massive grits. Contemporary degradation of the ancient landslide complexes is evident along the coast comprising erosion and small-scale failures of the coastal cliffs and episodic large-scale run-out of mudslide lobes onto the beach. Sediments deposited on the foreshore in this way are rapidly removed and contribute to the extensive beach known as Cayton Sands.

The southern section of Cayton Bay is fault bounded; considerable thicknesses of glacial till form the coastal cliffs in the central part of the bay. These are subject to small scale rotational slips and mudslides. The till capping thins rapidly towards Yon's Nab, where for a short section landslides are mostly absent.

Rock outcrops are present at the southern limit of the Bay and in the centre of the Bay, seaward of Killerby Cliffs.

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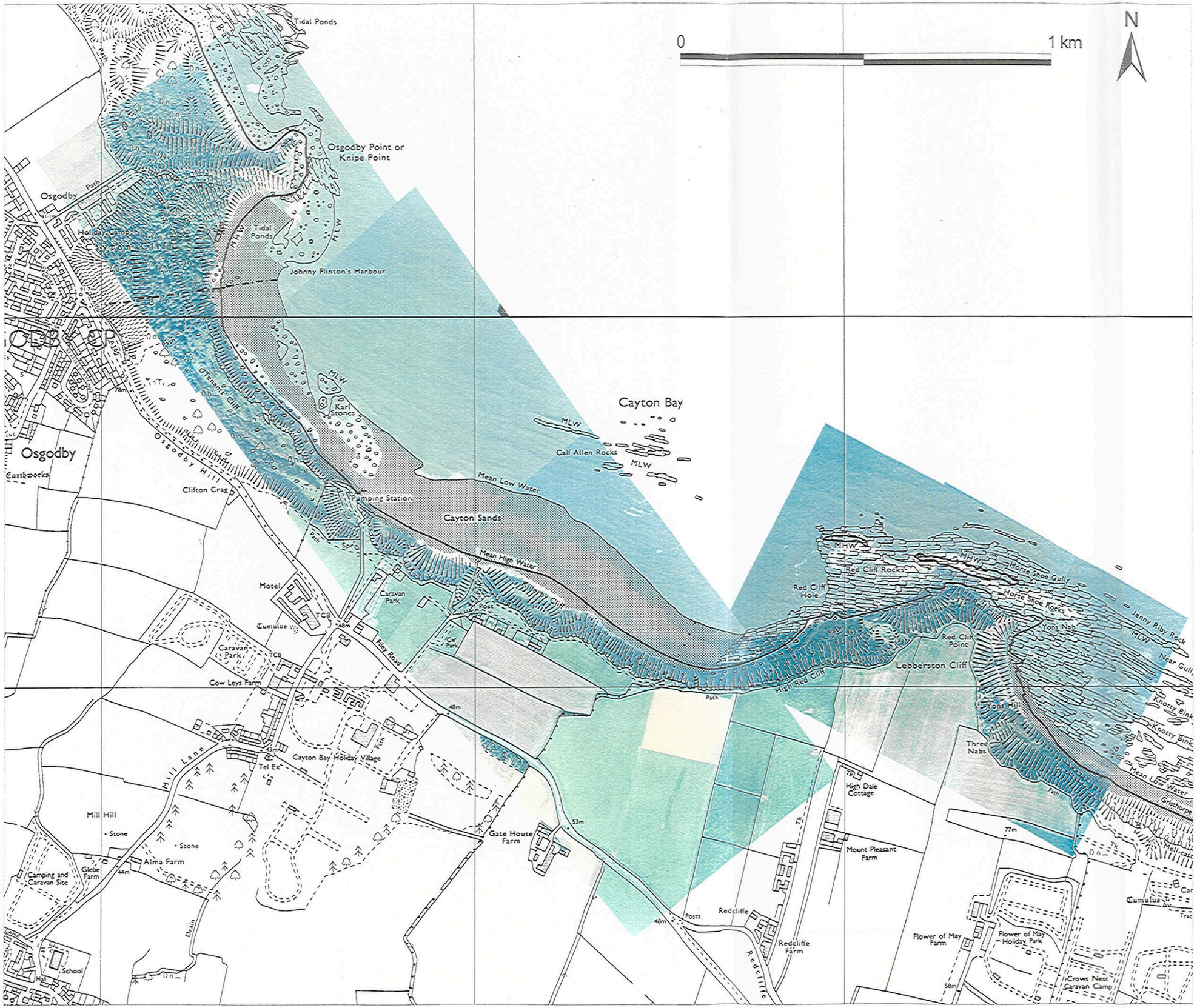
Cayton Bay - aerial survey, October 1999



REV NO:	FIGURE NO:
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2.2.2 *Solid Geology*

From north to south the general sequence of solid rocks is as follows:

- Knipe Point: Kellaway Rock
- Cayton Bay: Lower Calcareous Grit underlain by Oxford Clay
- Red Cliff Point: Interbedded mudstones and sandstones

2.2.3 *Superficial Geology*

The area is mantled by glacial deposits (till) formerly known as drift or boulder clay. The till consists of permeable and impermeable layers that represent alternating lodgment and flow tills intermixed with fluvio-glacial sands and gravels. Where exposed in coastal cliffs, the glacial till has a profound influence on the nature and potential for rapid erosion and landslides.

The glacial till provides a capping to the solid rocks exposed in the coastal cliffs and where the solid strata dip below sea level, as in the central part of Cayton Bay, the cliffs are formed entirely of glacial till.

2.3 *Foreshore Topography and Seabed Bathymetry*

Bathymetry data for the study area was identified from Admiralty Chart 129 which covers the coastline from Whitby to Flamborough Head (scale 1:75,000). The data on this Chart is quite old, being taken from lead-line surveys conducted between 1830 and 1932.

As much of the survey data on this chart is from surveys in the late 19th and early 20th Century, a bathymetric survey was commissioned as part of the Strategy Study to provide more up-to date survey information.

Beach profile data was unavailable, so a topographic survey was completed in conjunction with the bathymetric survey. The survey was completed in November 2000 and is documented in Annex A. The survey data is included in the enclosed CD.

The bathymetric and topographic survey was completed along several profiles within the Bay, extending to 2km offshore or to the -10m contour, whichever was closest to shore. Several beach sediment samples were taken along three of these profiles, as shown in Figure 2.2, and sediment grading analyses were completed. The median sediment size, D_{50}, derived from the grading analyses is given in Table

2.1 at each of the three profile locations that are considered further in the modelling studies.

Profile No.	Location	D_{50} (mm)
1	Cayton North	0.24
2	Cayton Central	0.325
3	Cayton South	0.38

Table 2.1 Median beach sediment grain size (see Figure 2.2 for locations)
Note: the median grain size (D_{50}) is the diameter exceeded by 50% of the sediment sample

The foreshore of Cayton Bay has rocky outcrops, notably at the southern end in front of Yon's Nab, seaward of Killerby Cliffs and at Knipe Point. There are deposits of boulder size material both at the cliff toe and in the inter-tidal zone, at Knipe Point and to the north of the concrete defences at Tenant's Cliff. The solid rock features strongly influence the seabed bathymetry. In the northern part of the Bay, sea bed contours are closer together, resulting in rapid increases in water depth moving offshore. In the southern end of the Bay, rock outcrops provide protection, resulting in shallower water depths closer to shore.

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CAYTON BAY
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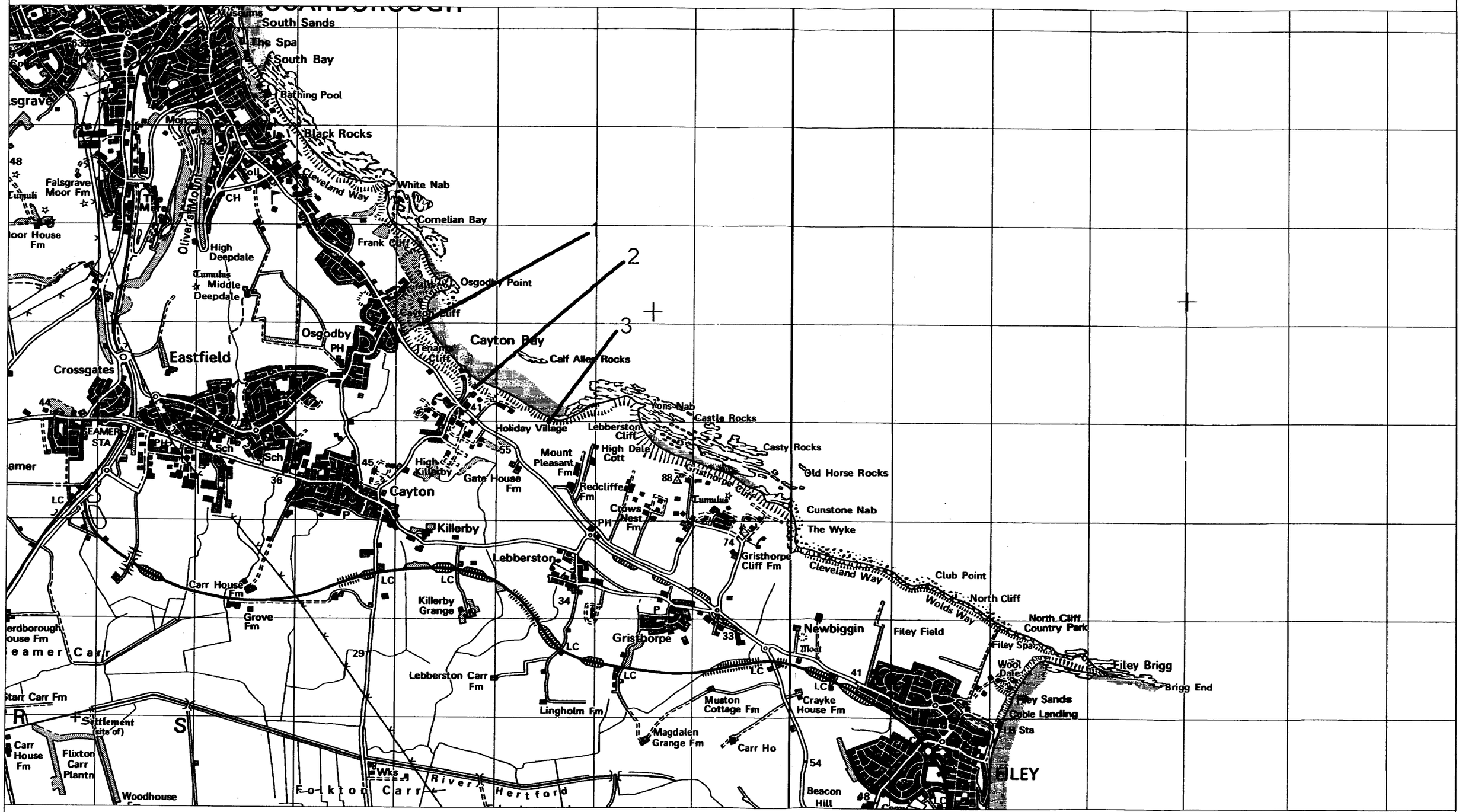


Locations of Survey Profiles

Figure 2.2

N

0 1 2 3 Kilometres

3 Hydrodynamics

3.1 *Water Levels*

Water levels in the Bay were derived from information given on the Admiralty Tide Tables for Bridlington and Scarborough and are given in Table 3.1.

Water level	mCD	mODN
Mean High Water Spring (MHWS)	5.8	2.5
Mean high Water Neap (MHWN)	4.9	1.6
Mean Sea Level (MSL)*	3.52	0.22
Mean Low Water Neap (MLWN)	2.4	-0.9
Mean Low Water Spring (MLWS)	1	-2.3
CD**	0	-3.3

Table 3.1 Water levels in Cayton Bay

**No data available – Mean Sea Level at Scarborough given*

*** Interpolated from Bridlington and Scarborough*

3.2 *Waves*

Deep water wave conditions were extracted from the UK Met Office European Wave Model by HR Wallingford (1996) at three locations covering the SMP study area, the most southerly point of which is located offshore of Filey Brigg (54.25N 0.33E). A scatter table of offshore wave conditions for the period from January 1987 to December 1995 is given in Table 3.2.

As part of the SMP, extreme offshore wave conditions were derived at three locations. The most southerly point covers Cayton Bay. Wave modelling studies undertaken in conjunction with those for the Filey Bay Strategy Study, transformed the wave conditions given in the scatter table (Table 3.2) for the southerly point inshore to the –10mCD contour at three locations within Cayton Bay. Extreme wave conditions were also derived at these locations.

H1 to H2		P(H > H1)	Wave Direction (degrees true)												
			0 - 30	30 - 60	60 - 90	90 - 120	120 - 150	150 - 180	180 - 210	210 - 240	240 - 270	270 - 300	300 - 330	330 - 360	Total
0.00	0.50	0.99137	2848	1327	1057	688	415	411	323	407	323	300	559	1418	10076
0.50	1.00	0.89059	8180	2978	2263	1476	1460	1167	1152	1384	1533	1669	1685	4138	29085
1.00	1.50	0.59975	4875	1399	1354	1175	1129	1240	1415	1761	1757	1901	1555	4316	23877
1.50	2.00	0.36097	2654	688	856	871	685	901	1221	1171	1198	1323	1088	2118	14774
2.00	2.50	0.21323	1297	388	521	468	494	749	1099	821	620	742	715	1487	9401
2.50	3.00	0.11922	570	255	327	262	312	407	593	437	445	415	403	943	5369
3.00	3.50	0.06552	243	164	205	137	186	361	335	164	95	255	274	563	2982
3.50	4.00	0.03571	106	110	171	65	65	198	106	68	34	84	278	418	1703
4.00	4.50	0.01867	72	80	133	8	42	91	11	8	8	57	64	285	859
4.50	5.00	0.00989	30	27	87	23	8	30	11	19	0	38	42	251	566
5.00	5.50	0.00422	27	4	23	8	4	4	4	4	0	4	19	137	238
5.50	6.00	0.00186	8	0	23	0	4	0	4	0	0	4	8	49	100
6.00	6.50	0.00087	0	0	4	0	0	0	0	0	0	0	0	30	34
6.50	7.00	0.00053	0	0	0	0	0	0	0	0	0	0	0	11	11
7.00	7.50	0.00042	0	0	0	0	0	0	0	0	0	0	0	19	19
7.50	8.00	0.00023	0	0	0	0	0	0	0	0	0	0	0	0	0
8.00	8.50	0.00023	0	0	0	0	0	0	0	0	0	0	0	15	15
8.50	9.00	0.00008	0	0	0	0	0	0	0	0	0	0	0	8	8
Parts per thousand			209	74	70	52	48	56	63	62	60	68	67	162	991

Table 3.2 *Scatter Table of Offshore Wave Conditions at Met Office Wave Model point 54.25N 0.33E*

Notes: *1) Data is in parts per hundred thousand, with wave heights the significant wave heights in metres.*

2) P(H>H1) is the probability of Hs exceeding H1.

3) Total number of hours = 78888

4) Based on UKMO predictions for January 1987 to December 1995.

3.2.1 *Wave Transformation Modelling*

Wave transformation modelling was completed to derive wave conditions at inshore locations on the -10mODN contour, Figure 3.1 (also see Figure 2.2 for profile locations). These conditions were determined at the beach profile locations, in order that they could be used as input to the sediment transport modelling (see Chapter 5). The wave transformations were completed at Mean Sea Level (+0.22mODN at Scarborough).

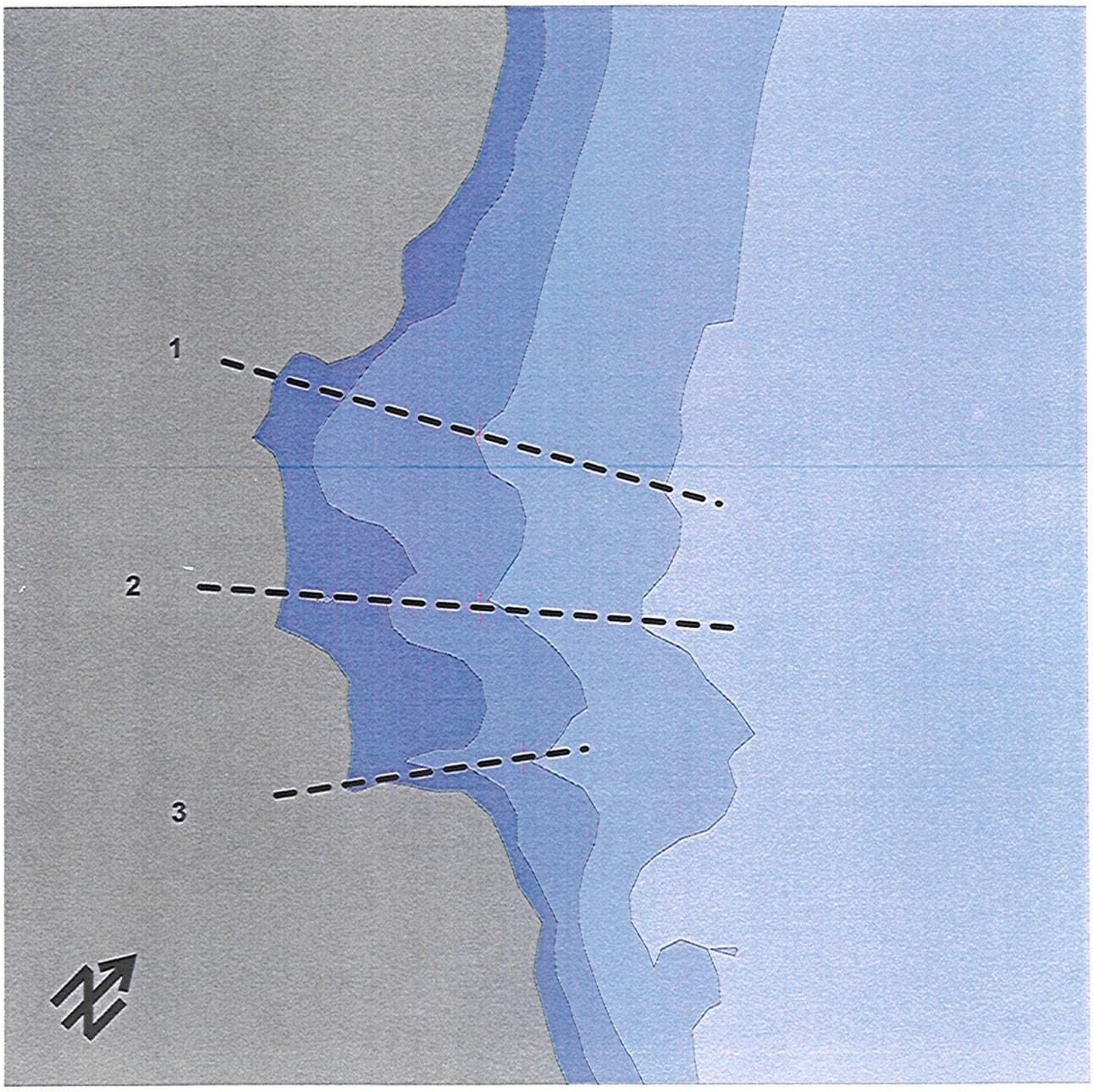
The modelling was completed using Halcrow's grid-based MWAVE_REG model. An interpolated bathymetric grid of the study area was produced from the digital information obtained during the recent survey (Annex A) and by digitising the available Admiralty Charts, as discussed in Section 2.3.

Wave conditions were extracted at the -10mODN contour at each of the beach profile locations, see Figure 3.1. For the extreme wave conditions, only waves between offshore directions 330° and 90° were considered, as these direction sectors have the highest frequency of occurrence of the largest waves. Extreme offshore wave conditions as given in the SMP were transformed to the inshore points for 1:1, 10, 50, 100, 200 and 300 year return periods and the offshore scatter table was transformed to each of the profile locations. The 300 year return period offshore significant wave heights were interpolated from graphs in the SMP as values were not given. A fixed wave steepness, s=0.05 was assumed, in accordance with the offshore wave data extracted from the Huntcliffe to Flamborough Head SMP. The offshore extremes are given in Table 3.3, for each direction sector considered. Extremes at each location are given in Table 3.4 for each return period, with significant wave height, H_s, mean wave period, T_m, and wave direction tabulated. The most severe wave conditions occur in the northern part of the Bay. Wave height contour plots for a range of conditions are given in Figures 3.2 to 3.8 [note that scale bars vary on these figures due to differing magnitudes of incident wave conditions].

Cayton Bay Strategy Study

Bathymetry and profile locations

Figure 3.1



Direction	345°		015°		045°		075°	
Return Period (years)	H_s (m)	T_m (s)	H_s (m)	T_m (s)	H_s (m)	T_m (s)	H_s (m)	T_m (s)
1	6.7	9.3	4.8	7.9	4.6	7.7	5.4	8.3
10	8.6	10.5	6.3	9.0	6.3	9.0	7.3	9.7
50	9.8	11.2	7.3	9.7	7.5	9.8	8.6	10.5
100	10.4	11.5	7.8	10.0	8.0	10.1	9.1	10.8
200	10.9	11.8	8.2	10.3	8.5	10.4	9.7	11.1
300	11.1	11.9	8.7	10.6	8.7	10.6	9.9	11.3

Table 3.3 Offshore extreme wave conditions (from SMP)

Return Period (years)	Cayton Bay (North) [1]			Cayton Bay (Central) [2]			Cayton Bay (South) [3]		
	H_s (m)	T_m (s)	Dir (°)	H_s (m)	T_m (s)	Dir (°)	H_s (m)	T_m (s)	Dir (°)
1	4.4	8.3	61	4.2	8.3	51	4.1	8.3	52
10	6.2	9.7	59	5.8	9.7	50	5.3	9.7	51
50	7.4	10.5	59	6.8	10.5	49	6.0	10.5	50
100	7.7	10.8	59	7.2	10.8	49	6.2	10.8	50
200	7.9	11.1	58	7.4	11.1	49	6.5	11.1	50
300	7.9	11.3	58	7.5	11.3	48	6.6	11.3	50

Table 3.4 Inshore extreme wave conditions at -10m contour

3.3 *Currents*

Tidal current data is available from a tidal diamond north of Cayton Bay (to the east of Scarborough Rock). These reach magnitudes of 0.7m/s on spring tides. Currents are in a southerly direction at high water and a northerly direction at low water.

Figure 3.2

Cayton Bay Strategy Study

Wave climate with boundary conditions:
Hs=8.6m, Tm=10.5s, Direction=075 degs (Ret. Per. = 50yrs)
Water level = 0.22mODN

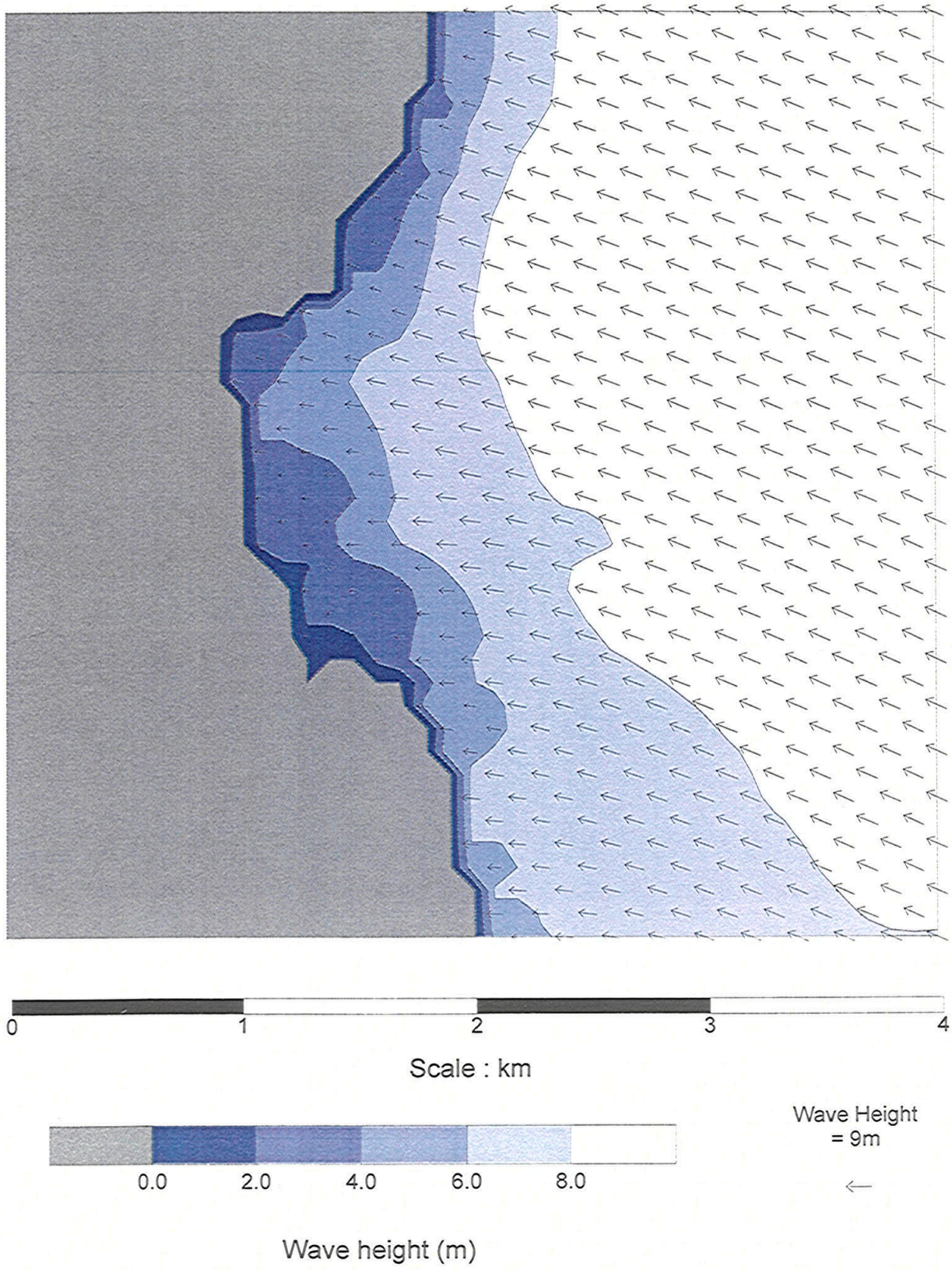


Figure 3.3

Cayton Bay Strategy Study

Wave climate with boundary conditions:
Hs=7.5m, Tm=9.8s, Direction=045 degs (Ret. Per. = 50yrs)
Water level = 0.22mODN

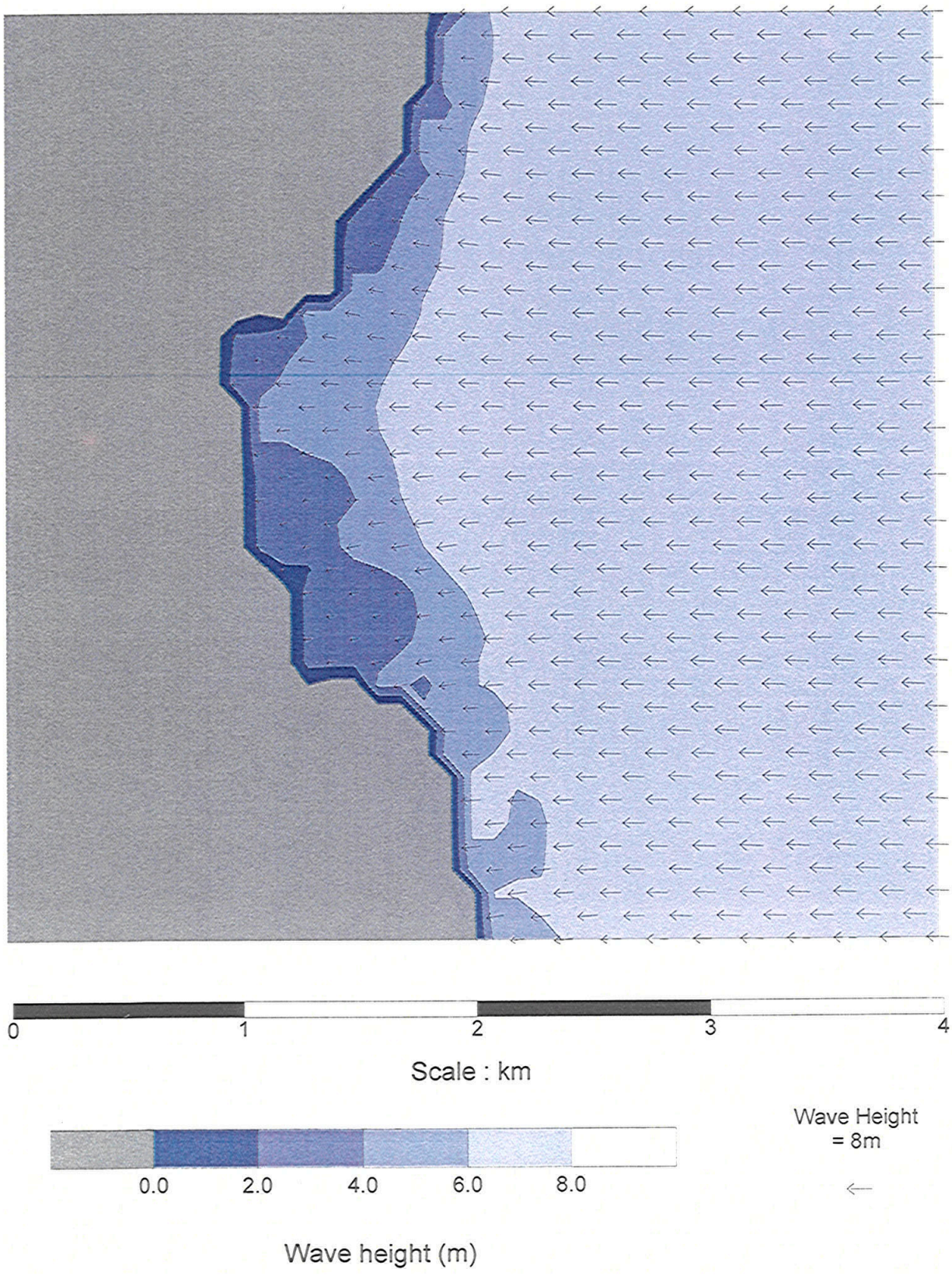
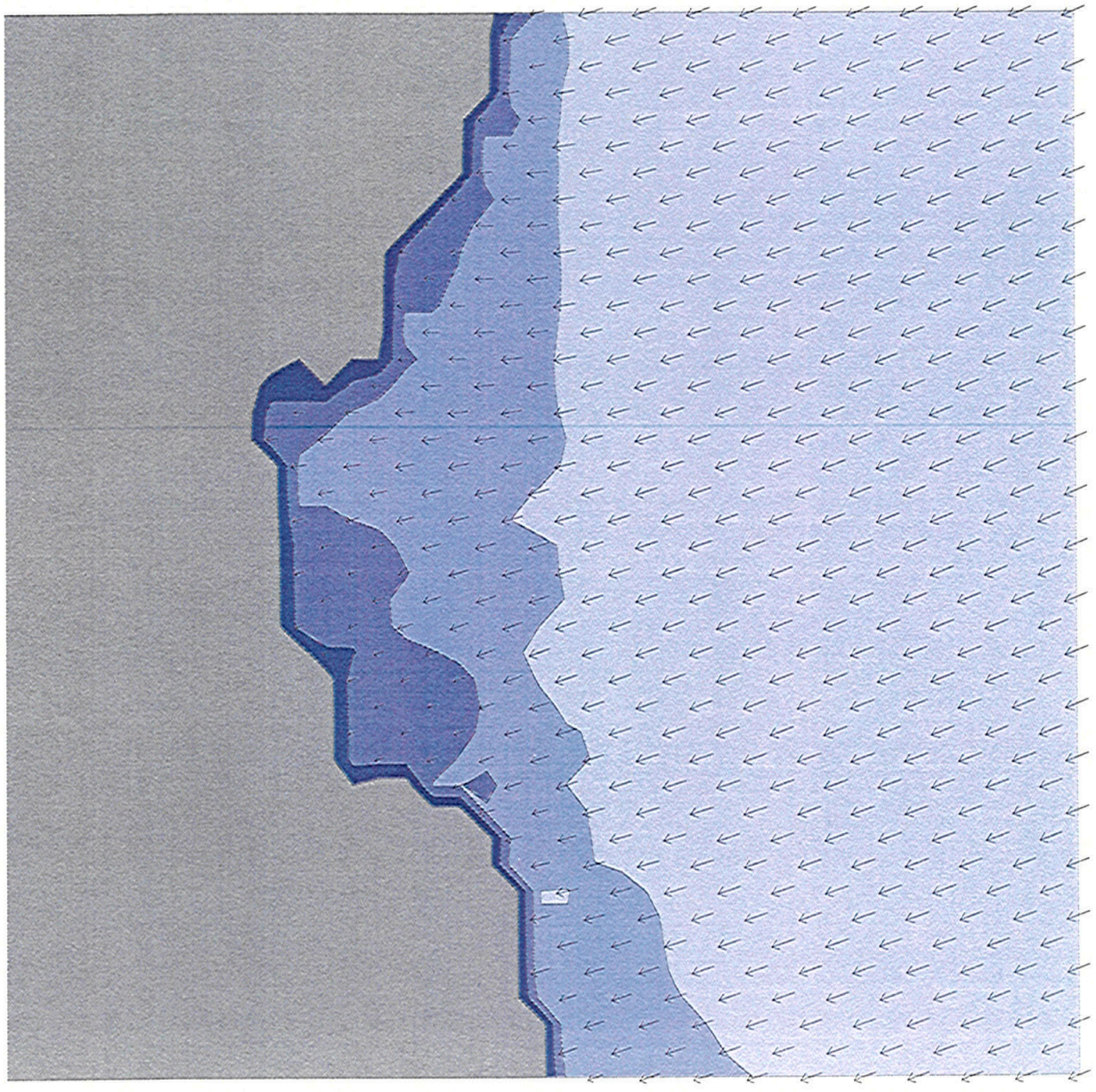


Figure 3.4

Cayton Bay Strategy Study

Wave climate with boundary conditions:
Hs=7.3m, Tm=9.7s, Direction=015 degs (Ret. Per. = 50yrs)
Water level = 0.22mODN



0 1 2 3 4

Scale : km

0.0 2.0 4.0 6.0 8.0

Wave height (m)

Wave Height
= 8m

Figure 3.5

Cayton Bay Strategy Study

Wave climate with boundary conditions:
Hs=9.8m, Tm=11.2s, Direction=345 degs (Ret. Per. = 50yrs)
Water level = 0.22mODN

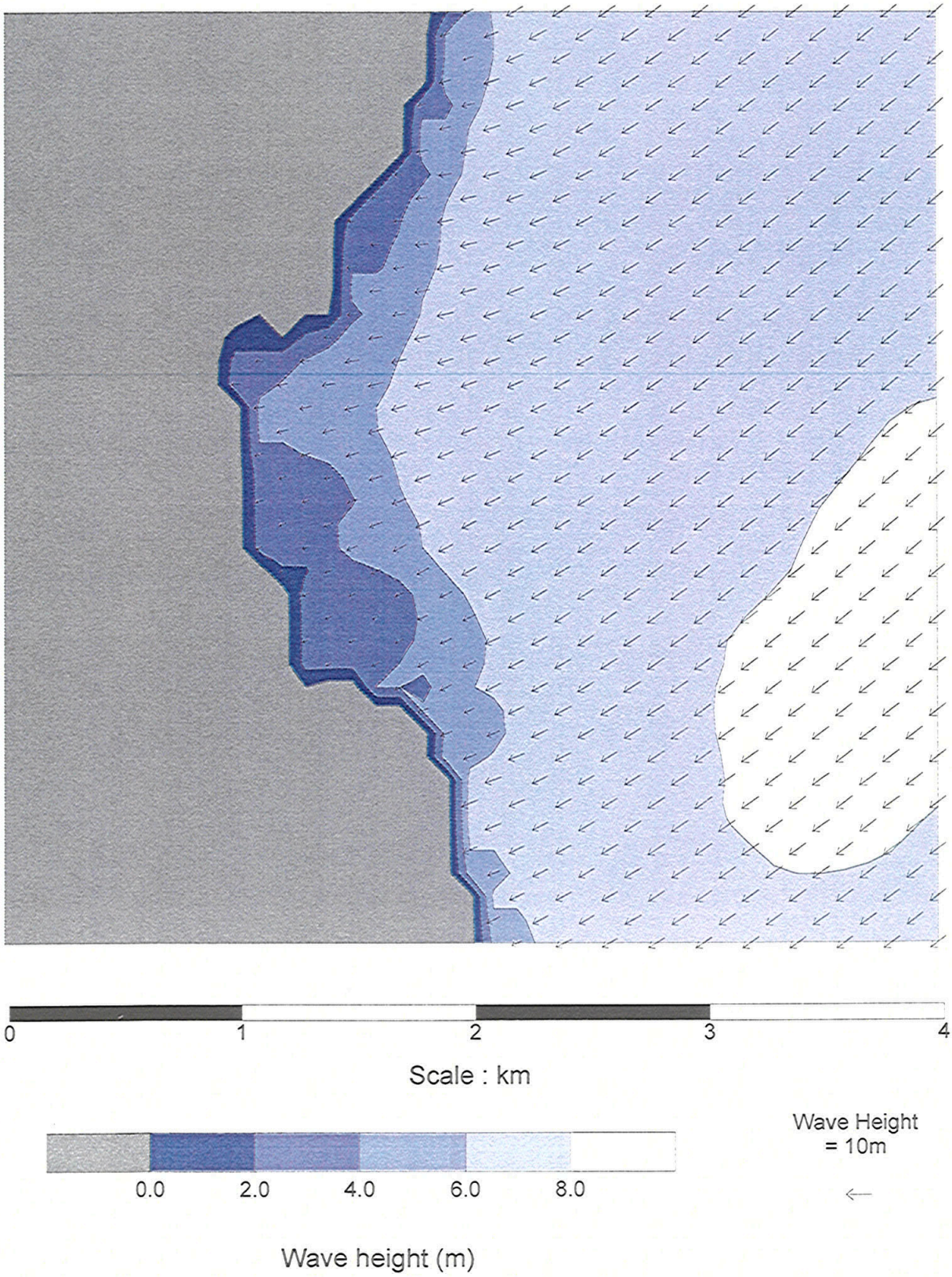
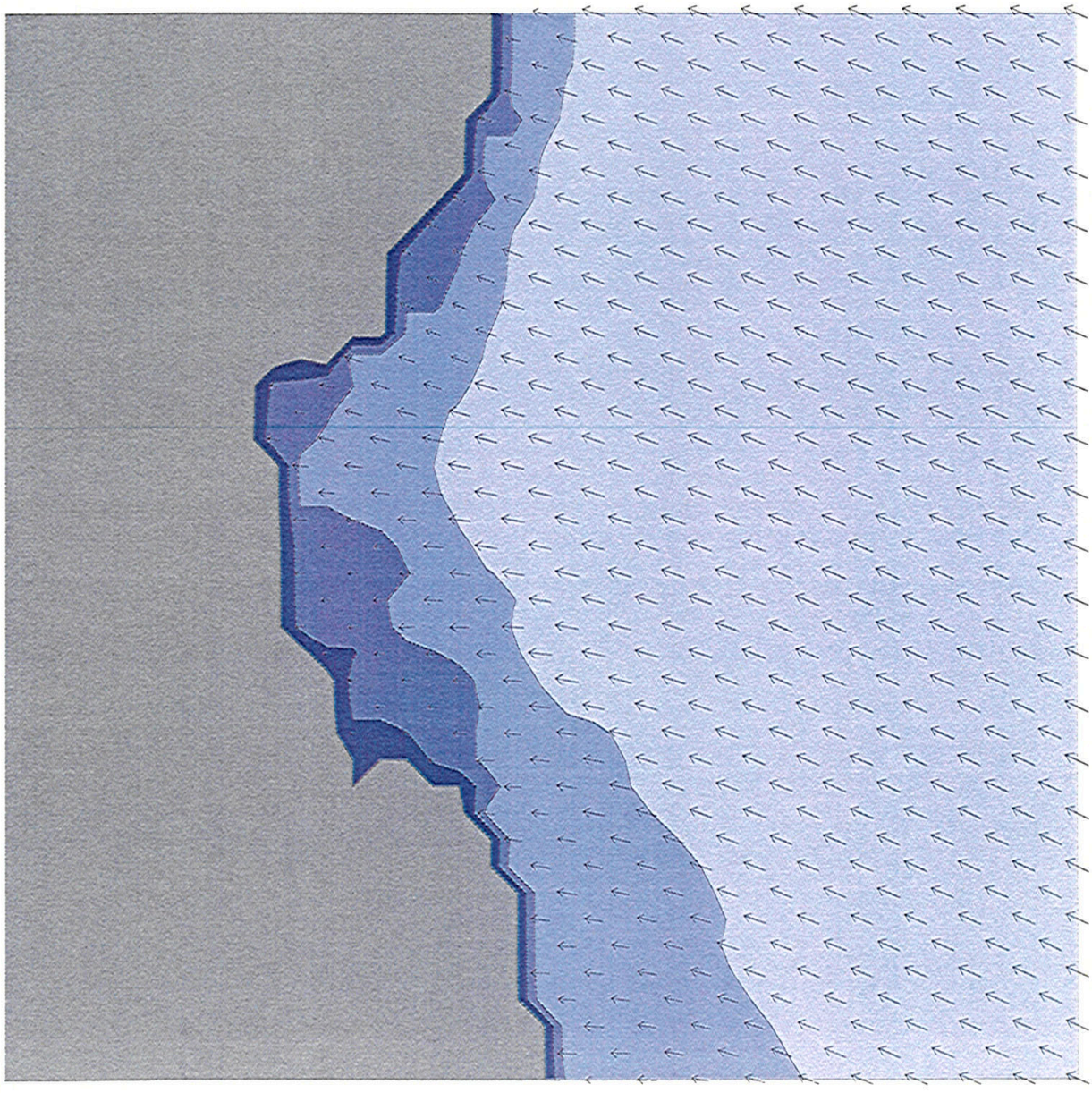


Figure 3.6

Cayton Bay Strategy Study

Wave climate with boundary conditions:
Hs=7.3m, Tm=9.7s, Direction=075 degs (Ret. Per. = 10yrs)
Water level = 0.22mODN



0 1 2 3 4

Scale : km

0.0 2.0 4.0 6.0 8.0

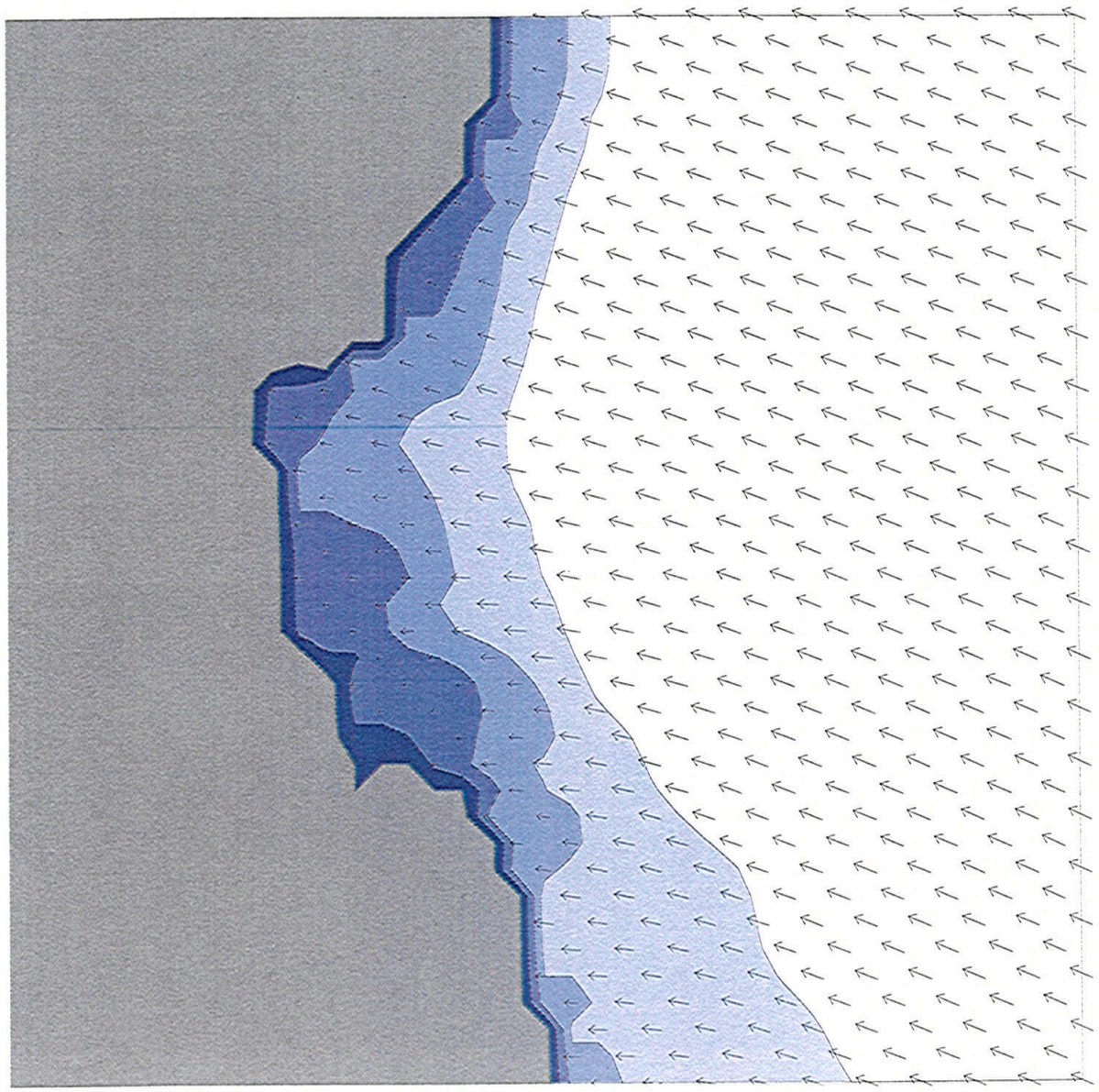
Wave height (m)

Wave Height
= 8m

Figure 3.7

Cayton Bay Strategy Study

Wave climate with boundary conditions:
Hs=9.1m, Tm=10.8s, Direction=075 degs (Ret. Per. = 100yrs)
Water level = 0.22mODN



0 1 2 3 4

Scale : km

0.0 2.0 4.0 6.0 8.0

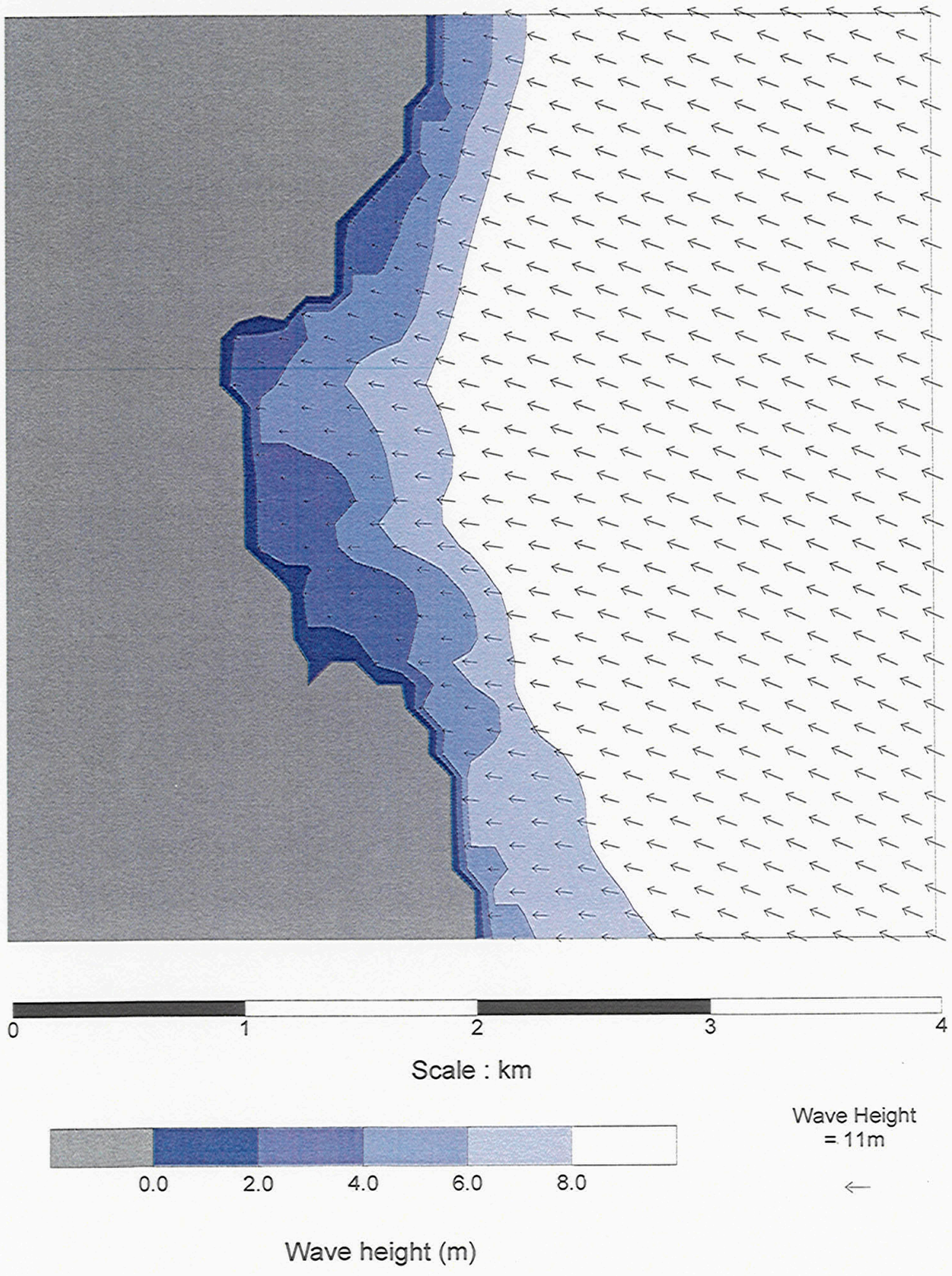
Wave height (m)

Wave Height
= 10m

Figure 3.8

Cayton Bay Strategy Study

Wave climate with boundary conditions:
Hs=9.9m, Tm=11.3s, Direction=075 degs (Ret. Per. = 300yrs)
Water level = 0.22mODN



4 Cliff Mapping / Assessment

4.1 *Introduction*

Existing coastal defences within Cayton Bay are limited to the small frontage of the disused pumping station. There is evidence to suggest that rock armouring may have been placed on the beach in the northern part of the Bay, probably as a measure to improve stability of Cayton Cliff. However, no information about these works has been found.

An important issue to be considered is the need to account for potential cliff instability and recession in future planning and decision-making. Equally important is the need to assess the contribution of cliff erosion in the maintenance and supply of materials to the extensive sandy beach, which is a major feature and asset of Cayton Bay.

In fulfilment of the above, detailed assessment of the cliffs has been carried out, comprising collation and review of existing information and new field surveys. The main objectives of this work were to assess potential cliff instability and recession throughout the Bay, consider the implications of failure of existing defences, and consider the effects of possible future coastal defences on the supply and distribution of sediments to the beaches.

The remaining sections of this Chapter explain the broad approach to this aspect of work, the findings of the cliff behaviour assessment and the conclusions that can be drawn from this with regard to the issues stated above.

4.2 *Approach*

Geomorphological investigations carried out in Cayton Bay have comprised a review of information, field observation and mapping, compilation of a database and reporting. These activities are described below.

4.2.1 *Information Sources*

Table 4.1 lists the information sources reviewed as part of the geomorphological investigations. They provide useful background information of a geological and geotechnical nature at a 'broad' strategic scale and for specific sites. The first two

references consider the nature of cliff recession and coastal processes in broad terms. Various site investigation reports provide data on local ground conditions.

Information	Date	Source
Huntcliffe to Flamborough Head SMP, Volume 1	1997	Mouchel Consulting Ltd.
Coastal Planning and Management: Applied Earth Science Mapping – Filey to Scarborough, North Yorkshire	1995	High Point Rendel
Cayton Bay: preliminary stability assessment - Technical report to North Yorkshire Highways and Transportation Department	1996	High Point Rendel
Site investigation report Knipe Point, Cayton Bay, North East Yorkshire	1981	Mills MSc thesis
Site investigation report	1975	Geo Research
Cliff recession rates	1960-	Various published sources (Annex C)
Coast protection survey	1946	Ministry of Health
• 1:250 000 solid/drift and offshore; sheet 54N 02W • 1:50 000 solid/drift sheet 55 (out of print); 1:63 360 sheet 54 • 1:10 000 solid sheets 18SW, 08SE, 08NE, 08NW	All	British Geological Survey

Table 4.1 Information Sources

4.2.2 *Geomorphological Mapping and Cliff Behaviour Assessment*

A geomorphological survey of the coastal cliffs at Cayton Bay was carried out during February 2001. The survey extends from Knipe Point to Yon's Nab.

The geomorphological survey comprised observation and mapping of cliff morphology, landslides, geology, materials, current cliff activity and recession potential. The field mapping used base maps at 1:1,250 scale. Field measurements of distance and cliff angles were made using a 30m tape and a compass clinometer, respectively. A photographic record of salient cliff and beach features was obtained during the survey (see enclosed CD), which has been cross-referenced to the cliff database.

Given the nature of geomorphological mapping, the accuracy of the information shown on the resulting maps should be regarded as approximate, with an 'on-the-ground' accuracy no better than 2m. The cliff angles are accurate to 1 or 2 degrees.

The field observations and measurements have been supplemented by additional information, most notably scaled measurements of distance from the base maps, interpretation of colour vertical aerial photography, oblique aerial video, and the available geological and geotechnical records (summarised in Table 4.1).

Using the field observations and supporting information, a geomorphological interpretation of cliff instability mechanisms and processes has been made (hereafter termed Cliff Behaviour Assessment). The approach provides an important spatial framework and vital clues as to the likely mechanisms, causes and consequences of cliff instability. The findings also provide an important context within which any future decisions on coastal management should be considered. The Cliff Behaviour Assessment provides the first detailed systematic evaluation of cliff instability and recession in Cayton Bay. The approach combines factual data with 'best judgement' (i.e. interpretation of landslide mechanisms and depth of cliff failure) to derive semi-quantitative estimates of cliff erosion and sediment supply to the beaches. As such the results should be regarded as preliminary and may be updated with findings from monitoring which should be used to validate and continuously review the findings.

4.2.3 *Database Compilation and Reporting*

The outputs of the geomorphological investigations comprise a series of maps, and a database, included in Annex D.

Map Series A (comprising 2 sheets) provides a summary of the main observations from the geomorphological survey and the spatial distribution of 'Cliff Behaviour Units'. Each cliff behaviour unit is coded and cross-referenced to the database and photographic record. The database provides detailed information on each cliff behaviour unit, based upon both factual and interpretative data.

Further explanation of the data entries is given in Section 4.3, which includes the following main parameters:

- Cliff Behaviour Unit types
- Geology
- Sediment Storage on Cliffs
- Cliff Recession Potential
- Cliff Sediment Input to Beaches

The database presents semi-quantitative estimates of cliff recession potential, sediment storage and supply from cliff erosion. It is recognised there are many uncertainties in estimating these parameters, as described further below (Section 4.3). Accounting for such uncertainties, the database includes upper and lower bound estimates for these parameters, which represent credible worst-case (i.e. high erosion) and best-case (low erosion) scenarios, respectively. In reality, it is considered that the more likely scenario falls somewhere between the upper and lower bound estimates.

4.3 Cliff Behaviour Assessment

4.3.1 Cliff Behaviour Unit Types

To understand cliff recession something must be known of the conditions and processes operating on the foreshore and on the cliff (and, in many cases, behind the cliff). It was for this reason that the concept of a 'cliff behaviour unit' (CBU) was developed for the Soft Cliffs study commissioned by MAFF, now DEFRA (In press), as it provides an important framework for cliff management.

That study identified a range of CBU types that reflect different mechanisms and rates of sediment inputs, throughputs and outputs (see Figure 4.1). Those that apply to Cayton Bay are described below along with any variations of these that were observed during the geomorphological survey.

In the assessment of cliff storage for CBU's, account is made of potential 3D effects in subsurface geometry. For shallow planar mechanisms of cliff failure (i.e. simple and composite cliffs), subsurface edge effects are minimal and a small

reduction in volume (10% upper bound; 20% lower bound) has been applied. For simple and complex landslides, which may comprise deep-seated rotational failure mechanisms, 3D subsurface edge effects can be significant and a large reduction in volume (30% upper bound; 50% lower bound) has been applied.

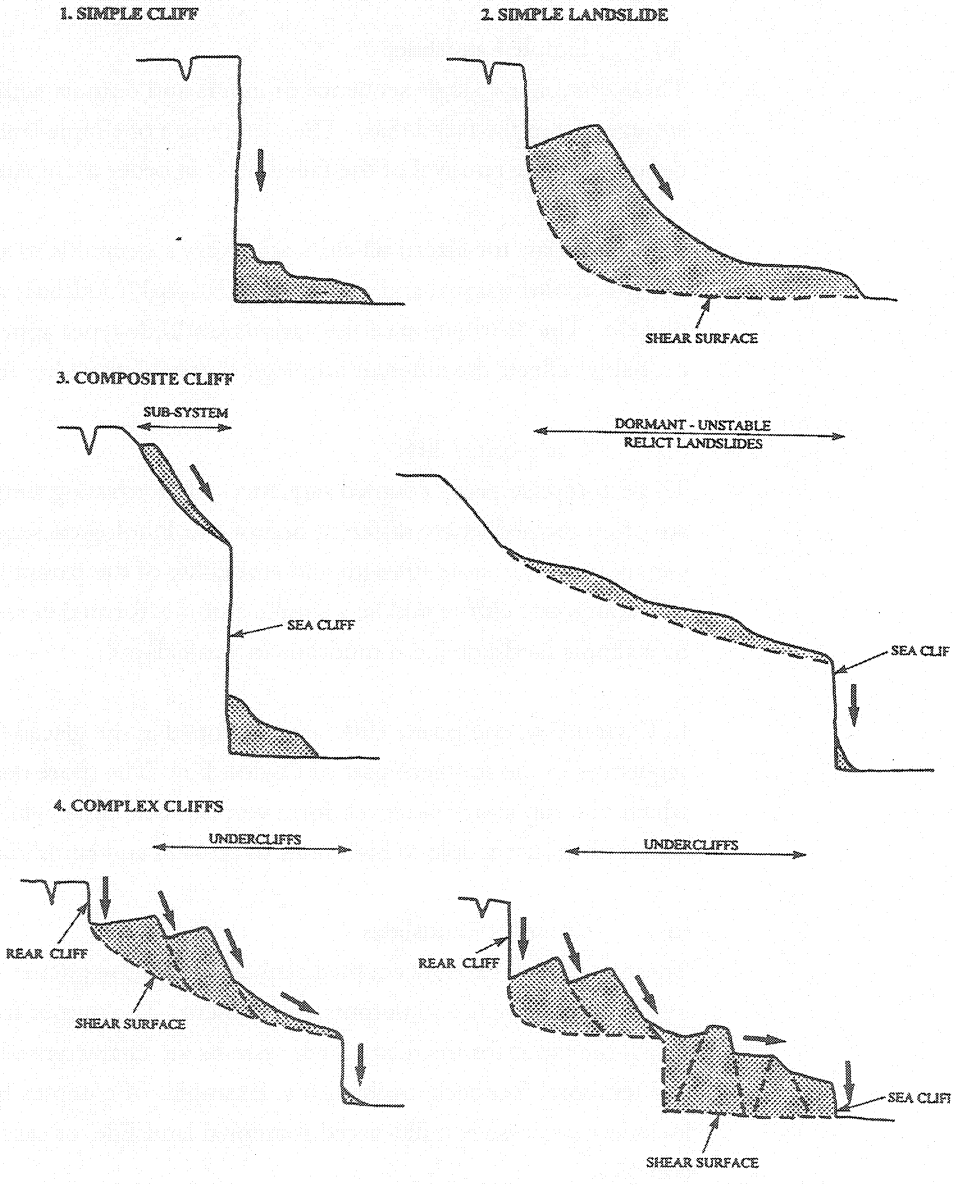


Figure 4.1 Cliff Behaviour Unit Types

(a) Simple Cliffs

These comprise a single sequence of inputs and outputs with limited storage. They are typically characterised by steep cliff faces and shallow erosion.

In Cayton Bay, simple cliff CBUs are developed in the landslide deposits of Tenants Cliff and on a small section of Red Cliff in the southern part of the Bay.

(b) Simple Landslides

These comprise a single sequence of inputs and outputs with variable amounts of storage within the failed mass. The occurrence of simple landslides is episodic and depends on the removal of the failed mass in order to initiate further landslides.

In Cayton Bay, the glacial till cliffs are highly susceptible to simple landslides. Deep-seated rotational and shallow translational (mudslide) mechanisms are present. The distribution of the various landslide types appears to be random and probably reflects the inherent lithological variability within the glacial till.

(c) Composite Cliffs

These comprise partly coupled sequences of contrasting simple sub-systems. They are often formed where different bedrock or lithological sequences introduce variations in the shear strength and erodibility of the parent materials. An example of a composite cliff would be a simple cliff (i.e. formed in resistant strata) overlain by a simple landslide (i.e. a mudslide in weak clays).

In Cayton Bay, composite cliffs are developed in the glacial till and bedrock sequences in the southern part of Cayton Bay. The more resistant Jurassic rocks, which outcrop above sea level, form vertical rock cliffs, while the weaker overlying glacial till is susceptible to high rates of erosion and landsliding.

(d) Complex Landslides

These comprise strongly coupled sequences of sub-systems, each with their own inputs, throughputs and outputs of sediment. The output from one sub-system forms the input for the next. Such systems are characterised by complex spatial and temporal feedback mechanisms. Examples of complex landslides would include a successive, multi-tiered rotational landslide, or cascading mudslide complex.

Two complex landslide systems are present within Cayton Bay at Tenants Cliff and Cayton Cliff. Further description of these complex landslides is presented in Section 4.3.4.

4.3.2 *Geology*

The geology of Cayton Bay is discussed in detail in Section 2.2.

4.3.3 *Sediment Storage on Cliffs*

An estimate of the volume of sediment stored within each CBU has been calculated based on measured and estimated parameters. These are described below with the numerical formula for estimating the volume of sediment stored.

(a) Cliff Morphology

Field measurements of cliff gradient were obtained for each CBU using a hand-held compass clinometer and by sighting from the cliff toe to cliff top, or vice versa. For composite CBU's (i.e. Killerby Cliffs), the cliff gradient was measured from the crest of the lower rock cliff to the cliff top. The height of the lower near-vertical rock cliff was estimated from field observation.

The plan length (in section) and width (longshore) of each CBU was scaled from the base maps. These dimensions and the cliff gradient have been used to estimate the cliff height, as follows:

$$\textit{Cliff height} = \textit{plan length} * \textit{Sin}\ \theta + \textit{height of rock cliff (if applicable)}$$

where, θ is the cliff gradient.

(b) Depth of Cliff Failure

The depth of cliff failure has been estimated from field observation. For simple and composite cliffs, depths of failed sediments were typically shallow ranging between 0.5m and 2m. For simple landslides, depths of landslide deposits ranged between 2m (i.e. for mudslides) and 15m (i.e. for rotational slips) and for complex landslides depths of about 30m were estimated. Estimates were made from direct observation of the exposed debris mantle or from an appreciation of the 3D geometry of the CBU and previously published data.

To account for uncertainty with this parameter a 50% reduction in depth was applied to the lower bound estimate.

(c) Sediment Storage Estimation

A numerical estimation of the volume of sediment stored on the cliffs has been calculated from the cliff morphology and estimated depth of cliff failure, as follows:

*Sediment storage = slope length * width * failure depth * 3D correction*

where the 3D correction accounts for subsurface geometrical edge effects (see Section 4.3.1).

4.3.4 *Cliff Recession Potential*

The recession potential for each CBU was assessed from field observation and supporting information. This included classification of the current activity of the cliffs, the recession potential (i.e. cliff top retreat) and estimated frequency of occurrence.

(a) Cliff Activity

Cliff activity was evaluated from field evidence of landslides and erosion. A distinction has been made between simple and composite cliffs subject to surface erosion processes, and simple and complex landslides subject to deep-seated ground movements. Vegetation density (i.e. % cover) was used as an indicator of activity for cliffs subject to surface erosion processes, whereas evidence of relic or active rotational and differential shear movements and toe heave were used for landslides. In this way, the activity for each CBU was rated according to the following classification (Table 4.2):

Activity Status	Activity %
Dormant (defended shoreline)	0
Inactive	25
Marginally Stable	50
Active	75
Very Active	100

Table 4.2 Cliff Activity Rating

To account for uncertainty with this parameter the upper bound recession potential has been factored up by one class (i.e. 75% from 50%) to account for the possible increase in activity due to the effects of climate change and sea level rise.

(b) Cliff Recession Potential

The cliff recession potential (or potential cliff-top retreat) has been estimated from historical records and field observation. As for cliff activity, a distinction has been made between cliffs and landslides, as the magnitude and frequency of recession

events are dependent on the mechanism of cliff failure. For example, simple cliffs are generally in dynamic equilibrium, with the rate of erosion at the cliff toe in balance with the rate of retreat at the cliff top, with only minimal time-lag response. Landslides, on the other hand are rarely at equilibrium, as the presence of landslide blocks or debris storage on cliffs provides a temporary buffer (or natural protection) against the de-stabilising effects of toe erosion. Only when a significant portion of debris has been removed through toe erosion will the cliff top be subject to mass failure once more. For large-scale landslides this cyclical response can take many years, decades or even centuries.

It is important to note that displaced landslide debris (i.e. the sediment stored on cliffs) will be subject to creep and/or occasional ground movement throughout this cycle in response to groundwater and erosion at the toe of the cliff.

There are few published cliff recession rates for this coastline (Annex C). The published data for Yorkshire indicates a range of erosion rates between <0.1 to 1.12m/year. Rendel Geotechnics (1993) presented data for Osgodby and Tenant's Cliff from an analysis of OS maps between 1911-1938, indicating erosion rates of 1.11m/year and 0.5m/year, respectively. The high erosion rates are generally reported for cliffs formed of glacial till with the lower rates reported for cliffs formed of more resistant bedrock, such as the grits and limestones.

It should be realised that published erosion rate data are very specific to individual sites and the methods used, reflecting the unique geological fabric and degree of wave exposure of sites, and the inherent sources of error with various methods and information sources. It is inappropriate and misleading to apply published rates of erosion from specific sites to make predictions of coastal change along adjacent coasts, except where it can be demonstrated that the geological and wave forcing conditions are comparable.

Cayton Cliff Landslide Complex (see Annex D maps, Cliff Behaviour Unit A)
This landslide complex abuts the steep-sided Knipe Point ridge to the north and the Tenants Cliff landslide complex to the south. The rear scarp is adjacent to the kerb of the main coast road. The area is extensively wooded and characterised by poor drainage. In contrast to Tenants Cliff (discussed below), the Cayton Cliff landslide is developed in up to 30m of glacial till overlying the Oxford Clay and Kellaway Rock.

The landslide complex comprises a series of retrogressive rotational slides developed primarily in the glacial till, but with a deep-seated basal shear surface within the Oxford Clay, and in the toe area, the Kellaway Rocks. The landslide is active, as evidenced by tension cracks and ground distortions over much of the area. These movements are degradational and appear largely contained within the existing boundaries of the landslide complex, with only minimal failure of the sides and rear scarp.

Mills (1981) carried out a geotechnical investigation at Cayton Cliff. This work identified three distinct soil units within the glacial till comprising sandy/coarse units interbedded with laminated and sandy clay tills. Similar lithology was found at Holbeck Hall after the dramatic landslide there in 1993. The importance of this is that the silty clay tills are considered to control the nature and mechanism, as they are likely to be brittle (i.e. large difference between peak and residual strength) and prone to progressive failure.

Cayton Cliff has been affected by a number of notable landslide events in the past:

- The Coast Protection Survey noted that "some years ago a huge slip occurred at a point a short distance north of the pumping station and left a vast crater about a quarter of a mile in width" (Ministry of Health 1946).
- The rear scarp settled by around 2m over a 50m length between 1926 and 1938, resulting in the relocation of the road carriageway 20m inland. A similar event to this had occurred between 1850 and 1890 along an adjacent section of rear scarp.
- In May 1969 a large failure occurred on the flank of Knipe Point ridge (GeoResearch 1975).
- In the winter of 1974 and 1975 movement occurred part way down Knipe Point Ridge.

- At the time of Mills' (1981) investigations, numerous small active rotational and translational slides were recorded on the flanks of Knipe Point ridge and on the rear cliff beneath the main coast road.
- Observations during this study identified localised failure of Knipe Ridge, causing settlement of the coastal footpath, and ground movements within Cayton Cliffs landslide complex.

Based on the foregoing, a number of potential landslide scenarios apply at Cayton Cliff:

- Small-scale failure of the rear scarp causing localised settlement of cliff top land (up to 50m). Over the next 50 years the likelihood of this scenario is considered high.
- Major reactivation within the current boundaries of the landslide complex resulting in the run-out of debris onto the beach. Evidence of eroded debris lobes and boulders arcs on the beach attest the relative frequency of events of this nature and it is considered that similar events are likely over the next 50 years.
- Initiation of major landsliding involving rapid loss of cliff top land. Continued degradation of the landslide complex has historically caused steepening of the rear and edge scarps. The stability of these has decreased in time and there is increasing potential for first time failure of these scarps in the future. It is not possible to predict when such an event may occur as little is known of the stress regime. Over the next 50 years it has to been assumed that such an event is likely, the probability increasing in time. High-Point Rendel (1996) postulated that major landsliding of this nature can be expected every 100-250 years and is likely to be similar in form and mechanism to the Holbeck Hall landslide. The latter event involved the rapid loss of 60m of cliff top land.

Tenants Cliff Landslide Complex (see Annex D maps, Cliff Behaviour Unit B)
This large-scale deep-seated landslide is immediately to the south of the Cayton Cliff complex, and extends from the southern limits of Osgodby village to Cayton Bay Pumping Station. The cliffs are developed in Oxford Clay, which is capped by the harder Lower Calcareous Grits (exposed in the rear cliff). A <5m thin cover of glacial till mantles much of the area. The landslide comprises a series of elongate 5-10m high ridges parallel to the shoreline beneath a 25-30m high vertical cliff (Figure 4.2).

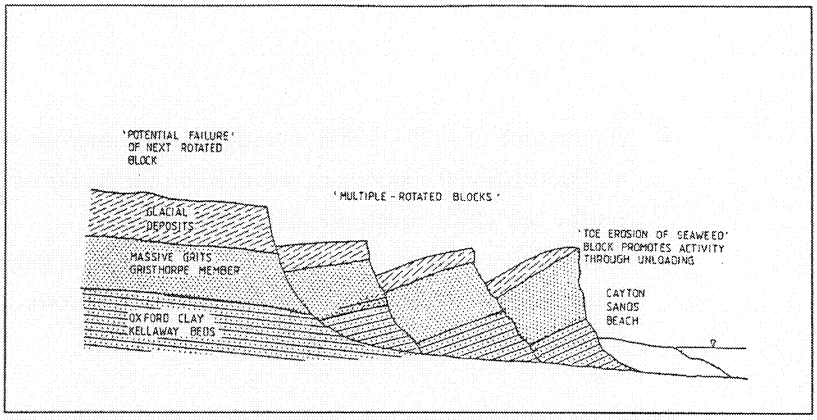


Figure 4.2 Section through Tenant's Cliff landslide complex

The landslides may be regarded as ancient, related to past climates and sea level. The landslides are currently marginally stable with the mass of displaced blocks providing a considerable toe restraint and support to the cliff. This apparent stability is supported by the absence of recorded cliff-top recession over the period 1910-1980. There has been localised small-scale failure of the rear scarp, where around 2m was lost between 1910 and 1926 (Rendel Geotechnics 1996). A similar event was observed during this study, whereby reactivation of tension cracks about 30m across occurred on the steep rear scarp following a very wet period.

The potential for major landslide movement involving significant loss of cliff-top land is low, and probably can only take place once marine erosion has removed a large part of the landslide debris that provides a considerable 'natural' passive restraint to further landslide movements. Cliff top recession will be preceded by widespread reactivation of ground movements within the existing landslide complex. The more likely scenario for the next 50 years is for continued erosion of the sea cliffs with relative inactivity within much of Tenants Cliff. Localised small-scale failures of the rear scarp, involving the loss of 2m or less of cliff top land may occur from time to time. For these reasons the stretch of existing road set back above the rear scarp of Tenants Cliff is not considered to be significantly at risk along this section, although this risk may increase within the strategy lifetime.

Based on historical records and field observation, the recession potential for each CBU has been rated according to the following classification. To account for uncertainty with this parameter, two estimates of the most credible minimum and maximum cliff top recession events have been recorded (Table 4.3). The upper bound estimates account for potential increases in sea level rise (5mm/year) and seasonal increase in rainfall and groundwater levels, due to the possible effects of climate change.

Cliff-Top Recession Event	Upper Bound	Lower Bound
Low erosion	0.5m	0.2m
Moderate erosion	1m	0.5m
High erosion	2m	1m
Landslip (small <0.2ha)	20m	10m
Landslip (moderate <1ha)	50m	25m
Landslip (large >1ha)	100m	50m

Table 4.3 Cliff Recession Potential Rating

(c) Frequency of Recession Events

The frequency of cliff top recession events ranges from annual losses due to ongoing erosion to infrequent losses due to discrete landslide events. There are few records from which reliable estimates of landslide frequency on the cliffs at Cayton Bay can be made.

Given the uncertainties with this parameter, it has been assumed that the recession of cliffs due to erosion is realised on an annual basis, whilst recession caused by infrequent landslide events of various size will be realised over a 50 year period from now. However, there is no certainty that landslide events of the magnitudes predicted will occur over the next 50 years, yet the risk remains.

4.3.5 *Cliff Sediment Input to Beaches*

The potential supply of sediment to the shoreline from each CBU has been based on the estimated cliff sediment storage, the magnitude and frequency of erosion and landslide events, current cliff activity and estimated sediment grading of the various soil and rock types.

(a) Cliff Sediment Loss Estimation

Numerical estimation of the sediment supply (annual erosion and episodic landslides) from cliffs was calculated as follows:

$$Cliff\ loss = Storage * Recession\ potential / slope\ length * Activity$$

For the composite cliffs at Cayton Bay, account is taken of the potential sediment loss from the erosion of the lower rock cliff.

(b) Cliff Sediment Grading

Not all sediment eroded from the cliffs provides material suitable for retention on the shoreline and beaches at Cayton Bay. The glacial till deposits provide the main

source of material, other than localised outcrops of Jurassic sandy limestones, calcareous grits and interbedded mudrocks and sandstones. Landslide debris from Cayton Cliffs and Tenants Cliff comprise disturbed Lower Calcareous Grits and glacial tills and likewise potentially provide a significant source of sediment in the northern part of the bay.

Little is known of the sediment gradings of the various sediments other than visual observation, which was recorded during the geomorphological survey. From observation of materials exposed in each CBU, an estimate of the proportion of the coarse, medium and fine sediments was recorded. It is noted that considerable variability in the composition of the glacial till is apparent.

(c) Effective Supply of Sediment to Beaches

An estimate of the volume of sediment likely to be retained as beach material has been calculated based on the estimated annual erosion and episodic landslide inputs of sediment from the cliffs and the estimated cliff sediment gradings. It is assumed that all coarse and medium sediment is retained in the beach and that only fine sediment is lost to the sea. In this way, the annual and episodic inputs of sediment from the cliffs of Cayton Bay is calculated as follows:

*Input to Beach = Annual or Episodic Cliff loss * (Coarse % + Medium%)*

The average annual sediment supply has been estimated from the sum of the annual erosion inputs plus the episodic inputs divided by their estimated frequency (such as 50 years).

4.4 *Discussion*

The Cayton Cliff Database and cliff mapping are included in Annex D. The maps are divided into three series (each comprising 2 sheets):

A – Cliff Behaviour Units
B -- Cliff Recession Potential (upper bound)
C – Planning Guidance

The Cayton Bay Cliff Database provides a detailed breakdown of each Cliff Behaviour Unit, which is cross-referenced to the various drawings. The length of coast covered by the assessment is about 3km.

The database includes lower and upper bound estimates of cliff storage, annual erosion, and episodic landslide inputs to the beaches. The upper and lower bound estimates represent credible worst-case (i.e. high erosion) and best-case (low erosion) scenarios, respectively. The results are summarised in Table 4.4 below.

Cliff inputs	A. Inputs from cliff erosion per year (m^3/yr)	B. Total inputs due to episodic failure over strategy duration (m^3)	C. Effective annual inputs averaged over strategy duration (m^3/year)
lower bound	3,700	156,300	7,100
upper bound	20,200	871,500	40,700

Table 4.4 Estimated sediment supply from cliffs for Cayton Bay

The results indicate that sediment inputs from ongoing erosion of the cliffs at Cayton Bay are comparatively low compared to the potential inputs from episodic landslide events, which have been estimated to potentially contribute over 1M m^3 during the next 50 years. The very large difference between the lower and upper bound values reflects the uncertainties with the geometry and potential magnitude of landsliding, particularly those associated with the complex landslides at Cayton Cliff and Tenant's Cliff. It is noted that these two landslide complexes account for approximately two thirds of the upper bound estimate, and are therefore a key store and supply of sediment within the Bay.

There is great uncertainty with the frequency and likelihood of landslide events occurring during this period and it has been assumed that the estimated contribution from episodic landslide events will be realised over the period of the strategy. Given this assumption, the average annual sediment supply at Cayton Bay has been estimated to be between 7,100 to 40,700 m^3, of which 3,700 to 20,200 m^3 is derived from ongoing erosion of the cliffs. The 'strategic' importance of the episodic landslide inputs cannot be overstated and any intervention to prevent this natural process would significantly harm the sediment budget and sustainability of Cayton Beach.

Maps B.1 and B.2 (in Annex D) show the recession potential of the various cliff units, together with the worst-case 50 year recession potential scenario.

The information given on these maps, and on Maps A.1 and A.2 has been used to provide future planning guidance for the coastal cliffs in Cayton Bay. The guidance provides recommendations on appropriate planning and development controls in zones of varying risk of recession along the coastal frontage. The three planning guidance zones are reproduced in Table 4.5 and reference should be made to the planning guidance maps C.1 and C.2.

Setting	Development Recommendations	Development Control
Coastal Cliffs	Area most unsuitable for development due to ongoing active coastal erosion. Development proposals subject to major constraints.	Should development be considered, a detailed Stability Report by a competent person would normally be required prior to any planning application. Many planning applications in this area may have to be refused due to the potential impacts of coastal erosion.
Coastal Landslides	Area most unsuitable for development due to ongoing active landslides. Development proposals subject to major constraints.	Should development be considered, a detailed Stability Report by a competent person would normally be required prior to any planning application. Many planning applications in this area may have to be refused due to the potential impacts of coastal landslides.
Cliff-top Consideration Zone	Area which may or may not be suitable for development due to potential cliff-top recession and instability. Site investigation and monitoring may be required prior to proposals being made.	A detailed Stability Report prepared by a competent person would normally be required prior to any planning application. The stability of the site and adjacent land should be evaluated with regard to the design-life of the development proposals and the potential impacts of cliff-top recession and instability.

Table 4.5 Planning Guidance

5 Coastal Processes

5.1 *Sediment Transport*

Sediment transport modelling completed as part of the strategy study served two key purposes:

- to establish longshore drift trends, to improve understanding of sediment movements within the Bay
- to assess cross-shore response of the beach under storm conditions, to identify whether the stability of defences may be compromised or erosion of the cliff toe may occur.

5.1.1 *Longshore Transport*

In order to further develop an understanding of sediment movement within the Bay, the COSMOS2D model was used to quantify potential longshore drift rates at various locations within the Bay. COSMOS2D is a 2-dimensional beach profile model for fine sediments (see Annex B).

Beach profile and bathymetry information, obtained during the survey completed as part of the Strategy Study, was used to set up the COSMOS2D model at 3 locations within Cayton Bay. Information on sediment grain size, obtained from grading analysis of beach samples collected during the survey work, was used as input to the modelling (see Table 2.1).

COSMOS2D was run for each of the wave conditions in the scatter table, given in Table 3.2 (after transformation to the -10m contour), with each condition weighted to represent its probability of occurrence. The outputs for all of the discrete conditions were then summed to produce a potential annual longshore drift rate at each profile location.

COSMOS2D transforms the offshore wave conditions inshore, taking into account refraction, shoaling, bottom friction and wave breaking, assuming shore parallel contours.

COSMOS2D was run in longshore mode for the 3 profiles, to establish the potential longshore drift. The model is run for each of the wave conditions in the

scatter table, given in Table 3.1, with each condition weighted to represent its annual probability of occurrence. The outputs for all of the discrete conditions are then summed to establish potential annual drift.

COSMOS2D transforms the offshore wave conditions inshore, taking into account refraction, shoaling, bottom friction and wave breaking, assuming shore parallel contours.

Wave conditions from 330-130° were considered in the modelling. Waves conditions in the scatter table from other direction sectors are assumed to be calm, in order that the sum of probabilities is equal to 1. Each wave condition is assumed to occur at Mean Sea Level (+0.22mODN).

The results are output after the final wave condition, giving the cross-shore variation in potential annual longshore drift summed over all wave conditions. As a constant sediment size was assumed across the full profile, longshore drift may appear to be taking place across a wider cross-shore extent than is actually the case. An assessment was therefore made of the width of the cross-shore profile that contributes to the longshore drift, based on seabed levels and sediment size, in order that an estimate of the total longshore drift at each location might be made. The longshore movement of material mostly occurs around the lower part of the profile, typically around the mean low water mark.

Results indicated that net longshore drift within the Bay is in a southerly direction. It should be noted that the limitations of the wave data available mean that the variability in drift due to differing wave conditions and directions cannot be established. Resulting potential drift rates from the modelling were high, however, without baseline data for calibration, it is not possible to fully quantify the drift rates within the Bay.

The modelling indicates an accretion of material in the centre of the Bay. This corresponds well with aerial photographs and maps, which indicate an accumulation of material behind the Calf Allen Rocks, with the rocks acting as a reef. The sea bed contours show that water depths are shallower in the southern end of the Bay, compared to the northern end, where the contours cut much further inshore. This results in greater nearshore water depths at the northern end and a narrower beach.

5.1.2 *Cross-shore storm response*

Cross-shore modelling was carried out to assess the effect of extreme storm conditions on draw-down of beach levels. This modelling was completed at Profile 2 shown on Figure 3.1, at the centre of Cayton Bay.

The COSMOS2D model was used, and it was assumed that each extreme wave event lasted for 24 hours. Tidal levels, from a typical spring tide curve, were derived at hourly intervals, giving 24 wave/water level events, each with a duration of one hour.

Profile changes arising from the 1-year return period storm, from 4 direction sectors (330-360°, 0-30°, 30-60° and 60-90°) were assessed, to establish the wave direction which caused the worst draw-down in beach levels (Figure 5.1). The greatest cut-back in the crest of the beach occurred for waves from 75° (60-90° sector). Beach levels at the toe of the cliff cut down to approximately 2.5mODN (approximately MHWS), suggesting that under extreme conditions, accelerated erosion of the cliff toe may occur as beach levels drop. It is of note that this may be most critical at the northern end of the Bay where the beach is narrower, sediment size smaller and beach levels lower. It is likely that the hard defences have an influence on beach levels, causing some lowering of levels at the toe of the wall, which will be accelerated during storm conditions.

The model became unstable when run for wave conditions of more extreme return period, most likely caused by the rock foreshore at the seaward extent of the profile.

5.1.3 *Overview of Sediment Processes*

The key sediment input into the Bay is from the eroding cliffs, as discussed in Chapter 4. It has been assumed that only the medium and coarse sediment will remain within the Bay and contribute to the sediment supply, with finer cliff material being carried offshore. The estimated average annual sediment inputs from the cliffs are between 7,000 and 41,000m^3 (see Table 4.4). These average inputs include both inputs due to gradual erosion and the potential inputs from large scale landslides within the Bay. It is considered that the probability of occurrence of large scale movement is small, but nonetheless the risk still exists within the strategy lifetime.

Generally, there are no obvious signs of beach growth within the Bay, with the exception of some build-up of material in the lee of Calf Allen Rocks. This

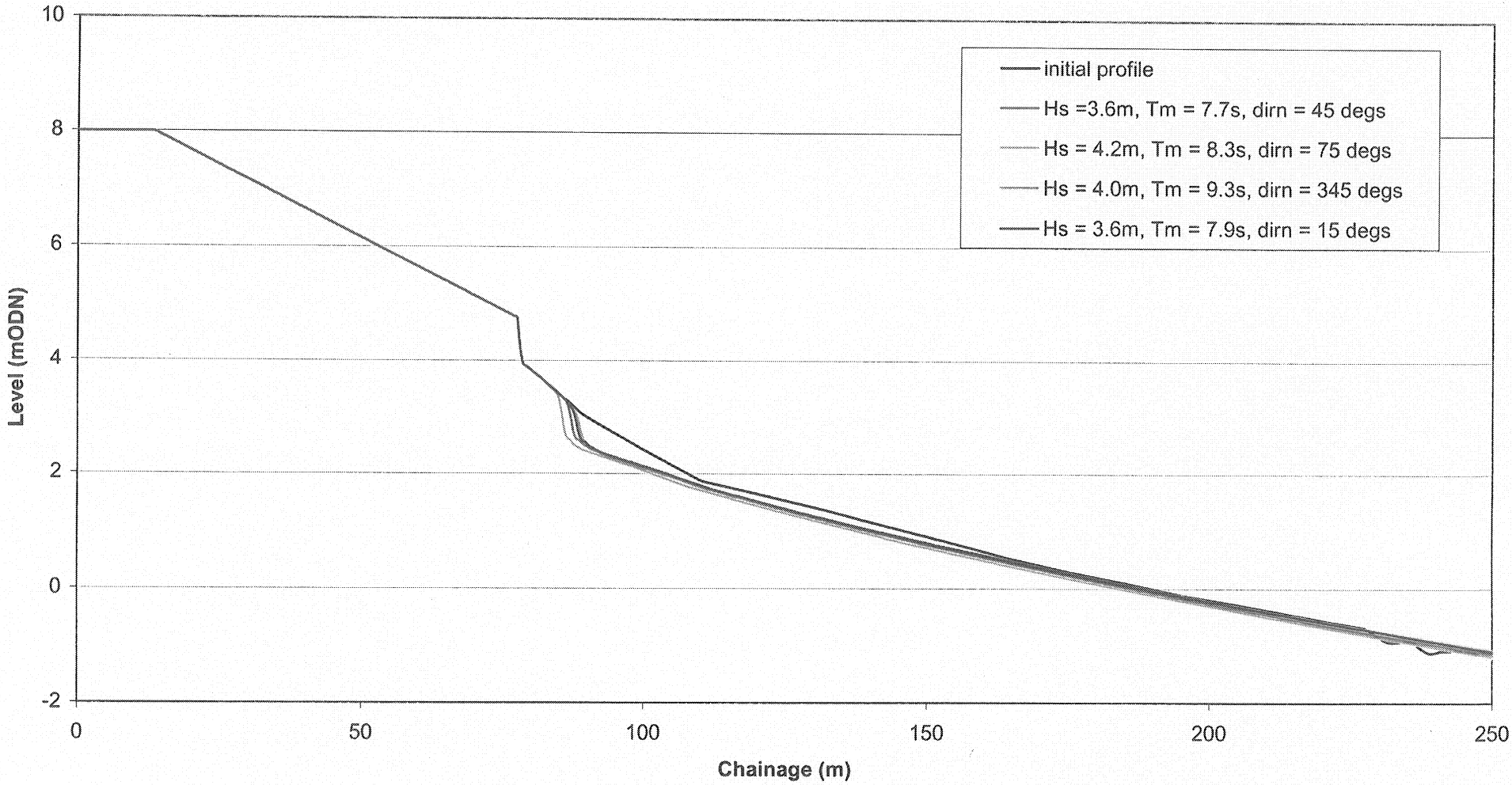
suggests that any material input from the cliffs either forms beach to replace the eroded cliff, thus adding to the volume of material stored within the Bay, or is lost offshore. There are indications of a build-up of material seaward of Calf Allen Rocks, indicated by a bulge in the seabed contours (out to the 10m contour) however it is not clear whether this results from sediment derived from within the Bay. Given the southerly drift within the Bay, it is possible that some of this material will be transported southwards.

There currently appears to be an adequate supply of sediment to the Bay from the unprotected cliffs, ensuring healthy beaches within the Bay. The continued natural erosion of the cliffs is important, without intervention measures to protect the coastline, to ensure that this sediment supply to the Bay is maintained.

There is some evidence that beach levels are lower in front of the hard defences. The strategy however recognises that these defences should be removed as they reach the end of their useful life, being replaced by alternative means of beach access. This will effectively increase the sediment input to the Bay as this section of cliff is allowed to erode naturally, and will avoid problems of scour at the toe of the vertical seawall.

Figure 5.1

Filey Bay Strategy Study : Profile 2 - Comparison of profile changes under 1 year return period waves from different offshore directions over a spring tide event



6 Coastal Defences

6.1 *Overview*

Much of the frontage of Cayton Bay is in its natural state with no man-made coastal defence structures. There are hard defences in Management Unit 24B, at the foot of Tenant's Cliff (see Figures 1.1 and 2.1). These are discussed further in Section 6.1.1.

6.1.1 *Cayton Bay (Unit 24B)*

This unit includes defences comprising a masonry and concrete seawall and apron, which protect a disused water pumping station and a single residential property, Figure 6.1. There is a division of ownership of these defences, between SBC and private owners, so options will need to ensure a unified management approach. There is significant damage to the defences at the southern end, Figure 6.2, with the concrete slab and apron being badly broken up in places. This presents a safety hazard to beach users, particularly given the close proximity to the beach access. Steps provide access to the beach at this point, with a kiosk located at the top of the steps. It is noted however, that in May 2001 SBC undertook short term repairs comprising provision of a concrete deck and grouting of the concrete rubble to form an apron.

Figure 6.1 Defences at Tenant's Cliff

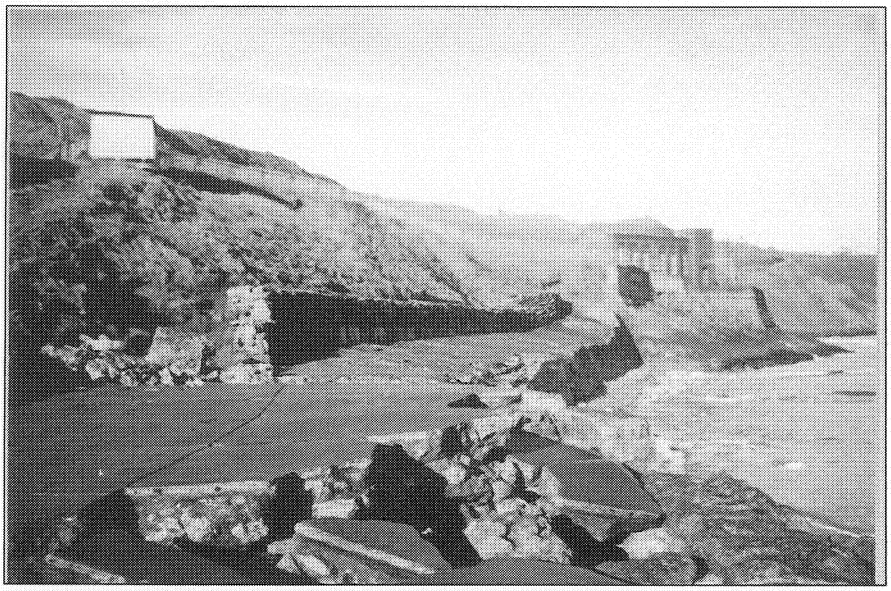


Figure 6.2 Damaged defences at south end of Tenant's Cliff

It is unlikely that these defences will be economically sustainable within the lifetime of the strategy, and consideration should be given to abandoning / removing these defences within the first half of the strategy lifetime as they reach the end of their useful life. The adjacent defences beneath the pumping station are in better repair, and it is therefore considered that these are less likely to fail within the early part of the strategy lifetime. However, given the continued cliff recession adjacent to the defences, it is possible that outflanking may lead to failure of the defences.

Continued monitoring should also address any potential problems as a result of toe scour, particularly as beach levels are lower at this location. This should be reviewed during the strategy lifetime. The need to continue protection of the disused pumping station may also be reviewed at later stages of the strategy.

These defences, as recorded in the most recent update (1997) of the 1993 Coast Protection Survey of England (CPSE) are summarised in Table 6.1. The assessment of condition and residual life is updated where appropriate.

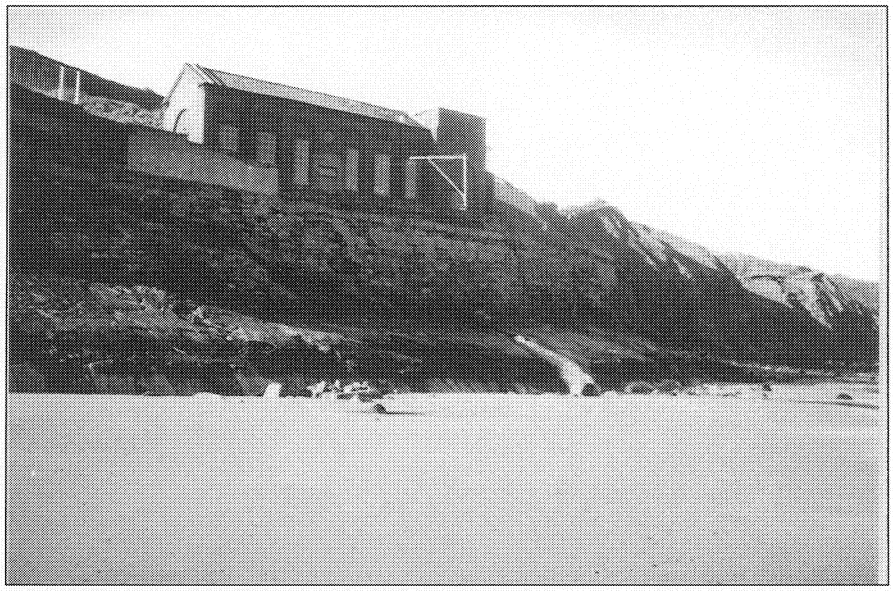


Figure 6.3 *Defences at disused pumping station*

Location / code	Length (km)	Crest level (mODN)	Type / material	Exposure/ Condition	Residual life (yrs)
Cayton Bay 240/6558	0.05	7.5	Seawall (masonry) Apron (concrete)	High Class 2	>10
Cayton Bay 240/6559	0.08	7.5	Seawall (masonry) Apron (stone)	High Class 2	>10
Cayton Bay 240/6560	0.10	7.3	Seawall (masonry) Apron (concrete) with masonry toe	Medium Class 4*	5-10
Cayton Bay 240/6561	1.00	50.0	Cliff (Clay)	High	

Table 6.1 Cayton Bay Defences

Notes:

* Some interim works have being undertaken to prolong structure life

Condition class definitions:

1 Condition as built

2 Some signs of wear, needs to be kept under observation; returnable to condition as built with simple maintenance, i.e. work advisable in order to prevent undue deterioration

3 Moderate works required; probably limited to a maintenance operation to return to satisfactory condition. i.e. work necessary to sustain adequate performance

4 Significant works needed; capital works probably required within 5 years

6.2 *Key Issues*

Some of the defences are likely to require removal / replacement within the first half of the strategy lifetime. The defences form a strong point in the centre of the Bay, which is not likely to be sustainable over the lifetime of the strategy. This is due to continuing cliff recession immediately adjacent to the defences, and to the limited extent of development protected by the defences, meaning that there is not an economic case for continued protection. This should be reviewed at interim stages during the strategy lifetime. As this location provides key public access to the beach, it will be important to maintain this access, given the amenity value of the beach to the local economy, and in particular the nearby caravan parks.

Management options are considered in more detail in Section 9, where recommendations are made for provision of beach access that can be managed throughout the strategy lifetime as the cliff position retreats.

7 Strategic Environmental Appraisal

7.1 *General*

Strategic Environmental Assessment (SEA) is the formalised, systematic process of evaluating the environmental impact of a policy, plan, strategy or programme. It provides an environmental overview and establishes environmental objectives at the strategic level.

This Strategic Environmental Assessment comprises:

- A description of the baseline environment, concentrating on aspects of the environment that are relevant to, or may be affected by, coastal protection and flood defence plans.
- Consultation with relevant statutory bodies and other organisations with an interest in the coastal zone.
- Establishing specific environmental objectives that the adopted coastal management strategy should aim to fulfil.
- Appraisal of specific strategy options, to evaluate the types of environmental impacts and benefits that they will generate.
- Recommendation of the most acceptable strategy option(s).
- Conclusions as to the positive and negative environmental implications of the proposed option.
- Identification of environmental issues that need to be addressed (for example, generic mitigation measures) as part of the implementation of the preferred option.

Strategic Environmental Assessment (SEA) follows a similar approach to project-level environmental assessment, but differs from it in that it is a high level overview setting broad objectives and identifying generic approaches. Consultation is undertaken with the aim of agreeing the objectives with a wide variety of stakeholders, and ensuring that the strategy is environmentally sustainable. The information necessary to complete a project level environmental assessment, such as engineering scheme design details, is not available at this stage. However, the SEA fulfils an important role in ensuring that the agreed strategy is, at least in outline, environmentally acceptable. By identifying and considering the most important environmental issues at this stage, it is intended to prevent a situation in which detailed schemes are developed that subsequently have to be

rejected or fundamentally re-designed to comply with legislation or other environmental requirements. By identifying strategic level issues that can be carried through to several projects or schemes, SEA also aims to minimise duplication of work later on. Hence, SEA occupies a central position in a hierarchy of studies, between shoreline management planning on the one hand and project environmental assessment on the other.

7.2 *Baseline Assessment*

7.2.1 *Introduction*

An account of existing environmental conditions that are relevant to coastal management in the study area has been undertaken focusing on the following areas:

- geology & geomorphology;
- water & aquatic environment
- ecology & nature conservation,
- landscape;
- land use & population
- tourism & recreation
- fisheries
- transport network & traffic
- cultural heritage
- planning/legislation

A summary of the most salient points from the environmental baseline has been reproduced below with the full SEA provided in Annex E.

7.2.2 *Summary of Environmental Baseline*

(a) Geology & geomorphology

Cayton Bay is a particular feature formed by faulting, with a sweeping sandy beach which extends offshore backed by low slumping glacial till cliffs that are vulnerable to landslip activity from a combination of wave action and ground water, creating a characteristic series of terraces and seepage ponds.

(b) Water & aquatic environment

The Bay is a designated Bathing Beach and its waters are tested on a regular basis by the Environment Agency to determine compliance. The Bay has met mandatory standards for total and faecal coliforms during 1999 and 2000, however it has failed to meet the more stringent guideline values for faecal coliforms in 1999 and

faecal coliforms /faecal streptococci in 2000. There are no designated Blue Flag award beaches within the study area, however, Cayton Bay has qualified for the Tidy Britain Group Seaside Award, achieving mandatory Bathing Water Directive Standards over the past six years.

Sewage treatment infrastructure within the study area includes waste water pumping stations at Killerby Cliff (inland) and Knipe Point. There is also a long sea outfall (continuous discharge to 2km offshore) and short sea outfall discharging at MLWS immediately to the north of the study area in Cornelian Bay. A private septic tank discharges onto Cayton beach from a property at the base of Tenant's Cliff adjacent to the disused water pumping station.

(c) Ecology & nature conservation

Cayton Bay falls within the Saltburn to Bridlington Maritime Natural Area and the entire study area is covered by some form of nature conservation designation, including two Sites of Special Scientific Interest (SSSIs) linked by a Site of Importance for Nature Conservation (SINC), shown on Figure 2.2 of Annex E. Key reasons for designation are as follows:

Cayton, Cornelian & South Bays SSSI:

Geological interest includes a composite section through rocks of Middle to early Upper Jurassic and the site also contains type fauna Cardioceras of the Buckowskii subzone. It is also an area of species rich grassland and semi-natural woodland with frequent springs and pools with important invertebrate assemblages of ground beetles and soldier flies. The intertidal area supports purple sandpiper and turnstone.

Gristhorpe Bay & Red Cliff SSSI:

The site contains exposures of Callovian (Upper Jurassic) rocks important in interpreting the history of the Yorkshire area and middle Jurassic plant bed exposures at Gristhorpe (included on the Global Indicative List of Geological Sites).

Lebberston and Gristhorpe Cliffs SINC

Those habitats within the study area include coastal grassland, bare ground, intertidal boulders and rocks associated with the wave cut platform, hard cliff, continuous bracken and scattered bracken.

(d) Landscape

Cayton Bay forms part of a stretch of coastline between Scarborough and Filey Brigg that is currently located between two separate heritage coast designations, the North Yorkshire and Cleveland Heritage Coast to the north, and the Flamborough Headland Heritage Coast to the south. The North Yorkshire and Cleveland Heritage Coast partnership has put forward a proposal for the extension of the Heritage Coast to include this area.

(e) Land use and population

The main land uses within the study area include agriculture (grade 3 – see Figure 2.3, Annex E), tourism, leisure and recreation, with fishing along the coast. The National Trust owns approximately 36 ha of land within the study area which is used for stock grazing. Settlements in close proximity to the study include Cayton and Osgodby with smaller residential developments at Knipe Point and Killerby Cliff and various caravan parks including the Cayton Bay holiday centre.

(f) Tourism and recreation

Tourism plays an important role within the study area, but formal tourist facilities are largely limited to those associated with the various caravan parks within the study area. However, there are numerous opportunities for informal recreation that allow enjoyment and appreciation of the natural assets of the coast including walking, cycling and watersports such as surfing, windsurfing, canoeing, diving, sea angling and swimming (see Figure 2.4 Annex E). Access to the beach is via a footpath at Killerby Cliff, woodland paths maintained by the National Trust and a private road at Tenants Cliff.

(g) Fisheries

There are no indigenous fleets of vessels within Cayton Bay, however, sizeable fleets located at Scarborough and Filey work the Bay. Shellfishing is undertaken within the bay by approximately six small fishing vessels (under 12 metres) laying pots for crab and lobster. A further six trawlers also operate within the Bay focusing on cod, whiting and all flat fish. Juvenile fish are found within the study area and fishing for Dover Sole is prohibited between the months of January and April.

(h) Transport network & traffic

The study area is adjacent to the A165 Filey coast road connecting Cayton Bay to Filey and Scarborough and the B1261 connecting Cayton Bay and Lebberston with the A64(T) to York and the A1. A highway scheme is proposed for the

Scarborough to Lebberston diversion in addition to a link road to the A64(T) through the Middle Deepdale / High Eastfield area.

(i) Cultural heritage

There is limited information on the Cayton Bay area as no survey work has been undertaken in this area. However, there is considerable potential for foreshore archaeology and various dykes, barrows and tumuli are located along the ridge of the cliff backing the bay. There are no settlements close to the shore, however it is possible human settlements may have been lost to erosion as it is believed that the coastline in Roman times was probably much further to the east of where it is today. The Defence of Yorkshire project has surveyed the Cayton Bay beach defence system which was sited during the second world war. This system is now unique along the North East coast in that it is the only site with an existing complex of pillboxes of this size.

(j) Planning

Planning constraints have recently become one of the main factors driving the development of coastal defence plans. This is due to the increasing awareness of the need for the conservation of landscape and biodiversity, and related legislation. The aim of this section, therefore, is to present the existing planning situation in North Yorkshire, in order to be aware of the policies and plans of relevance to coastal planning and defence. The section contains a discussion of international, European, national, regional and local statutory and non-statutory plans of relevance to the current study.

International level policy is intended to direct policy-making at lower levels, and is currently promoting the concept of integrated coastal zone management. Legislation at the EC level has a more direct effect, most significantly through the protection provided by the Birds and Habitats Directives.

At the National level, the Wildlife and Countryside Act 1981 provides legal protection for a range of species and arrangements for the protection of habitats. Local Councils are guided on Coastal Planning through PPG 20 on Coastal Planning, and regionally through Regional Planning Guidance Note 9, the North Yorkshire Structure Plan, and Minerals and Waste Local Plan. These regional plans are strongly focused on the protection of existing areas of landscape and nature conservation importance.

The Scarborough Local Plan contains general policies relating to planning and development issues, and specific policies relevant to particular areas and projects. Common themes are development in the coastal zone, on unstable land and close to coastal and other cliff edges, the protection of designated areas of conservation, landscape and archaeological importance, the issue of flooding and coastal erosion and coast protection works is also addressed.

Various other non-statutory plans reviewed include the SMP, LEAP and other planning documents produced by the County and Local Councils.

7.3 Environmental Objectives

The environmental baseline information (summarised above) and the views expressed by consultees, were used to define environmental objectives for the frontage. These provide a basis for the evaluation of strategic options put forward. The inclusion of a particular objective does not mean that it will necessarily be met by the strategy; indeed a number of objectives conflict with each other.

Due to the relatively small size of the study area, the majority of objectives are general (those applying to all or much of the study area, Table 7.1) with some specific objectives (those applying to individual coastal sections, Table 7.2) identified where necessary. Where there may be a conflict between objectives this has been identified in the Tables.

In formulating the objectives, account has been taken of the recommended policies in the adopted Shoreline Management Plan (SMP). However, the present study is much more detailed than the SMP. Accordingly, the SMP policies have been re-visited to take account of this new information.

Objectives for nature conservation assets have generally been framed in terms of habitats, rather than species. This is because, as a coastal defence strategy, the study is concerned with defining areas of land for management with respect to coastal and flood defences.

Table 7.1 General Environmental Objectives for the Whole Study Area

Assets	Objectives	Specific targets
Geomorphology		
Beach material	1. Any proposal for dredging marine aggregates should be rigorously assessed and only permitted if it can be shown that there would be no significant effect on beaches, coastal defence, the environment and other assets within Cayton Bay.	There should be no interference with the submarine cable that comes ashore at Killerby and wreck sites within the area.
Nature Conservation		
Sites of Special Scientific Interest	2. Habitats cited in or that support species cited in SSSI citations should be maintained and enhanced where environmentally sustainable and technically possible.	Cayton, Cornelian & South Bays SSSI: • Composite section through rocks of Middle to early Upper Jurassic • Type fauna Cardioceras of the Buckowskii subzone • Species rich grassland, semi-natural woodland with frequent springs & open pools • Invertebrate assemblages of ground beetles & soldier flies • Intertidal area supporting purple sandpiper & turnstone
		Gristhorpe Bay and Red Cliff SSSI: • Exposures of Callovian (Upper Jurassic) rocks important in interpreting the history of the Yorkshire area • Middle Jurassic plant bed exposures at Gristhorpe
Sites of Importance for Nature Conservation	3. Characteristic habitats and species should be maintained and enhanced *in situ* if environmentally sustainable, technically possible and consistent with other objectives, or otherwise provision made to re-create them elsewhere	Provision should be made for landward migration of cliff top habitats, including species-rich coastal grassland, bracken and bare cliff faces, as the cliff line recedes. There may be a need to facilitate re-creation of freshwater and brackish pools lost to erosion. Re-creation should only be undertaken in areas of low wildlife value, e.g. agricultural land. Overall objective should be to ensure no net loss of significant habitats.

Assets	Objectives	Specific targets
Characteristic habitats	4. Conserve and enhance within the study area if possible, the existing area and quality of habitats covered in the Biodiversity Action Plan (BAP). Where feasible a contribution should be made to meeting BAP enhancement targets.	A BAP is currently being produced which covers the area. UK BAP targets of relevance: Maintain and where possible enhance existing area and quality of: • Maritime Cliff and Slopes (including through use of mechanisms such as Countryside Stewardship) • Saline Lagoons
	5. Conserve, and contribute to sustainable management of characteristic wildlife habitats listed in Natural Area Profile and enhance any nature conservation features wherever possible	• Maintain natural processes of cliff erosion • Maintain or create buffer strips of semi-natural vegetation along cliff tops • Maintain natural processes, water quality and habitat value to birds of sandy and muddy shores • Maintain shingle and rocky shores
Characteristic species	6. Conserve and enhance within the study area if possible, the existing area and quality of habitats supporting species covered in the Biodiversity Action Plan (BAP). Where feasible a contribution should be made to meeting BAP enhancement targets.	Maintain present population and encourage sympathetic land management for: • Skylark • Song thrush Local BAP targets may be set for nationally scarce invertebrates associated with cliff seepages in the study area by the local BAP that is currently under production.
	7. Conserve and contribute to sustainable management of populations of characteristic and rare wildlife species listed in Natural Area Profile	Key components are: • Intertidal bird species (turnstone/purple sandpiper) • Invertebrates associated with soft cliffs (ground beetles / soldier flies) • Plants and animals of base-rich coastal grasslands • Species associated with rocky shores • Species characteristic of sublittoral sediments
Geological interest	8. Maintain the diversity of geological interest listed in the Natural Area Profile	• Maintain natural coastal processes • Maintain access to all recognised geological exposures
	9. Prevent physical damage to or obscuring of geological exposures that are designated as SSSIs	• Gristhorpe and Redcliff SSSI (see 1 above) • Cayton, Cornelian and South Bays SSSI (see 1 above)
	10. Ensure the possibility for use of geological sites for research and educational proposes.	• Studies of Callovian palaeogeography (High Red Cliff)

Assets	Objectives	Specific Targets
Landscape		
Coastal Landscape	11. Maintain, and where appropriate enhance, the character of the local landscape	• Sea Cliffs • Slumping glacial till slopes with characteristic vegetation • Ravines and associated vegetation • Wave cut beach platform with boulders and associated flora and fauna • Geological features such as strata, sequences, faults, folds, fossils and features associated with glaciation • wildlife features such as wading birds, cliff slope/woodland flora and littoral habitats
	12. Avoid the construction of sea defences or coastal protection that would adversely impact on landscape quality	There should be a presumption against visually intrusive hard defences to presently undefended cliff sections. Any proposed cliff protection must be assessed for its visual and landscape impact and the visual intrusion minimised.
	13. Protect important landscape elements from adverse coastal change or adverse impacts of coastal erosion, where environmentally sustainable, practicable and economic	Significant features to which this should apply include: • Osgodby / Knipe Point and wave cut platform • Soft cliffs of Cayton Bay • Promontory of High Red Cliff and wave cut platform
	14. Enhance or mitigate the effects of adverse landscape elements in the coastal zone, as part of implementing policies for coastal defence or managed realignment	Significant elements to which this applies include caravan parks, which should be set back from the coastline where possible, especially where threatened by coastal erosion, and accommodated in less visually intrusive locations and screened by existing landforms, woodland or appropriate tree planting
Recreation and Tourism		
Coastal Paths	15. The integrity of the existing Cleveland Way coastal path should be secured where feasible, sustainable and economic. Where coastal erosion or setback makes the existing route impracticable, it should be pro-actively diverted using relevant legal procedure, before it is lost.	Need to define mechanism and responsibility (Borough and County Councils, role of Countryside Agency and others)
	16. Opportunities should be sought to create new or extended Public Rights of Way in conjunction with appropriate coastal management projects such as cliff setback or protection	Need to define mechanism and responsibility (Borough and County Councils, role of Countryside Agency and others). Role of Countryside & Rights of Way Act 2000. Need to take account of wildlife protection and controlling disturbance on sensitive sites.
Public access	17. Maintain existing public access to the beach for pedestrians and water sports and seek opportunities to create new access points where appropriate.	Key access points at the base of Killerby Cliff, Cayton Cliff and Tenants Cliff should be maintained.

Assets	Objectives	Specific Targets
Recreational resources and visitor attractions	18. Protect significant visitor attractions and recreational resources in the coastal zone that are threatened by coastal change, where environmentally sustainable, practicable and economic. Otherwise provide for relocation of these assets to sustainable locations.	• Beach Cliff Kiosk • Car Park at Killerby Cliff • Caravan sites • Surf Shop and School at Killerby Cliff
Bathing Water Quality	19. Achieve compliance of designated bathing beaches with mandatory, and if possible with guideline, water quality standards	• Maintain existing mandatory standards at Cayton Bay and aim to improve to guideline standards
Fisheries		
Access to the sea	20. Maintain access to the shoreline for sea anglers within the Bay	
Fish stocks	21. Avoid adverse impact on fishing areas, including areas used for potting, fixed nets and trawling, and fish nursery areas from coastal defence works, including any barge deliveries and recharge activities	
Cultural Heritage		
Non-scheduled known terrestrial archaeological sites	22. Provide mitigation in the form of a watching brief, excavation and recording of known sites affected by coastal erosion, or retreat of the defence line, where appropriate.	In particular World War II defence system. Medieval shrunken village Osgodby
Undiscovered terrestrial archaeology	23. Consider providing mitigation in the form of assessment, excavation and recording within areas of high archaeological potential that would be affected by proposed sea defence or coastal protection schemes.	
Listed Buildings	24. Protect Listed Buildings from erosion or flooding where environmentally sustainable, feasible and economic.	
Wreck Sites	25. Avoid adverse impact on recorded shipwrecks or other recognised elements of the sub-tidal historic environment from any coastal defence works, including any barge deliveries and recharge activities	
Land Uses		
Commercial and residential property	26. Protect buildings from erosion or flooding where environmentally sustainable, feasible and economic.	Residential properties and Caravan Site at Killerby Cliff and Tenants Cliff.
	27. Avoid new development in areas prone to erosion or flooding risk during the lifetime of this Plan	
Road Infrastructure	28. Protect A165 road corridor	Consideration of policies for diversion of A165 Scarborough to Lebberston.

Assets	Objectives	Specific Targets
Agricultural land	29. Protect agricultural land from erosion or flooding where environmentally sustainable, feasible and economic.	National Trust grazing land and arable land at Killerby Cliff.
Economy and Community		
Economic Assets	30. Protect physical assets that provide a significant base for the local economy, including recreational resources, where environmentally sustainable, feasible and economic. Where this is not possible, provide for re-creation elsewhere.	Caravan Parks Yorkshire Water Pumping Station
Social assets	31. Protect physical assets that provide a significant base for local communities, including villages, where environmentally sustainable, feasible and economic. Where this is not possible, provide for re-creation elsewhere.	Infrastructure

Table 7.2 Specific Environmental Objectives for each section of coast (based on management units from SMP)

Management Unit (see Fig. 2.1, App. E)	Proposed Objectives	Implications of Proposed Objectives
24 A Cayton Bay (Knipe Point to Clifton Crag)	24.A.1 Maintain open sandy beach	Avoid constructing groynes
	24.A.2 Maintain pedestrian access to Cayton Cliff Woodlands	Potential conflict with objectives 24.A.3 and 24.A.4
	24.A.3 Maintain existing extent and quality of exposures of type localities of Tenants Cliff Member and type fauna of Buckowskii subzone (SSSI)	No active intervention appropriate
	24.A.4 Facilitate conservation or, if lost to cliff erosion, the re-creation of freshwater pool supporting tubular water-dropwort & possible populations of great crested newt	Limited intervention needed
	24.A.5 Maintain bathing water quality to comply with EU directive mandatory level	No implication for coastal defence policy
	24.A.6 Avoid disturbance to World War II defence system remains on beach, except where their deterioration presents a health and safety hazard and the need for removal.	Keep watching brief. Potential conflict with 24.A.9
	24.A.7 Protect cliff top property threatened by erosion and cliff slumping, if feasible, economic and sustainable	Potential conflict with objectives 24.A.3
	24.A.8 Maintain road infrastructure of A165 and proposed diversion	Potential conflict with objectives 24.A.3
	24.A.9 Maintain recreational value of beach	Potential conflict with 24.A.6
24 B Cayton Bay (Clifton Crag to High Red Cliff)	24.B.1 Maintain open sandy beach	Avoid constructing groynes
	24.B.2 Avoid interference with intertidal habitat and characteristic biotopes of Lebberston & Gristhorpe (SINC)	Potential conflict with objectives 24.B.3
	24.B.3 Create or maintain vegetated soft cliffs, allowing for landward migration as cliff recedes	No active intervention appropriate
	24.B.4 Avoid interference with intertidal and subtidal sandy and rocky habitat	No active intervention appropriate
	24.B.5 Protect cliff top property threatened by erosion and cliff slumping, if feasible, economic and sustainable	Potential conflict with objectives 24.B.2 and 24.B.3
	24.B.6 Maintain existing extent and quality of exposures of Callovian rocks and Gristhorpe Plant Beds (SSSI)	No active intervention appropriate
	24.B.7 Maintain bathing water quality to comply with EU directive mandatory level	No implication for coastal defence policy
	24.B.8 Maintain pedestrian access points to Killerby Cliff	Potential conflict with objectives 24.B.6
	24.B.9 Avoid disturbance to World War II defence system remains on beach, except where their deterioration presents a health and safety hazard and the need for removal.	Keep watching brief
	24.B.10 Maintain road infrastructure of A165 and proposed diversion	Potential conflict with objectives 24.B.6
	24.B.11 Maintain Cleveland Way footpath along Killerby Cliff	Potential conflict with objective 24.B.6
	24.B.12 Maintain recreational value of beach	Potential conflict with 24.B.9

7.4 *Implications of 'Do-Nothing' Policy*

The main implication of a "do nothing" policy would be continued, unmanaged retreat of the soft cliff coastal sections between Knipe Point and High Red Cliff, backing the sandy beach of Cayton Bay. This would lead to:

- Risk to property at Killerby Cliff, within the strategy lifetime;
- Risk to the single property at Tenant's Cliff, the adjacent disused pumping station, some risk to properties at Osgodby, Knipe Point and Clifton Crag, in the latter part of the strategy lifetime if significant landslides are reactivated;
- Loss of some Beach View caravan land and risk to bungalow at its seaward limit;
- No significant effects on statutory protected nature conservation sites which are reliant on continued slumping of the glacial till cliffs to maintain geological exposures and support invertebrate assemblages of ground beetles and soldier flies (SSSIs);
- Loss of vegetated cliff, cliff-top and associated habitats such as freshwater /brackish pools in the SNCI/SSSI, with no provision for set-back or recreation, leading to squeeze between the eroding cliff and existing land uses;
- Loss of agricultural grazing land and woodland owned by the National Trust;
- Serious adverse effects on landscape and visual amenity from deteriorating and collapsing defences and derelict properties, together with increasingly visually exposure of existing landscape elements such as caravan parks;
- Significant losses of recreational amenity, including some lengths of the Cleveland Way national coastal footpath, beach access points at Cayton, Killerby and Tenants Cliffs, and parking facilities at Killerby Cliff;
- Loss of non-scheduled known archaeological sites including remnants of the WWII defence system on the foreshore especially the complex of pillboxes;
- Possible impact on the submarine cable that comes ashore at Killerby Cliff (although this is understood to no longer be in use);
- Potential for breaching of the A165 if this is not re-routed further inland.

8 Assessment of Strategic Options

8.1 *Overview*

The management units proposed in the Shoreline Management Plan have been considered in turn to identify preferred management policies and options, taking into account environmental, technical and economic constraints. The methodology is outlined in this chapter, with the detailed assessment of each unit being discussed in Section 9.

8.2 *Strategic Options*

The policy recommendations made in the SMP were based on MAFF guidance for completion of Shoreline Management Plans published in 1995. Following completion of the Shoreline Management Plans, and as a result of the experience gained in their implementation, the guidance has been revised. A consultation draft is currently in circulation, due for formal publication later this year.

The guidance has evolved since the earlier publication and revised definitions of strategic policies have been produced. The options developed in this strategy are based on the new DEFRA guidance, but reference is made to the SMP policy recommendations and where alternative policies are proposed, this is highlighted. For clarity the policy options from the two sets of guidance are compared in Table 8.1, to allow easy cross-reference with the Shoreline Management Plan.

The policies from the latest guidance are:

- **Hold the existing defence line** by maintaining or enhancing the standard of protection.
- **Advance the existing defence line** by constructing new defences seaward of the existing defences.
- **Managed realignment** by identifying a new line of defence and where appropriate constructing new defences landward of the original defences.
- **Limited intervention**, by working with natural processes to reduce risks, whilst allowing natural coastal change. This may range from measures which attempt to slow down rather than stop coastal erosion and cliff recession to measures that address public safety issues e.g. promoting the build-up of beach material in front of unstable cliffs, or improving drainage of unstable coastal slopes.

- **No active intervention**, where there is no investment in coastal defence assets or operations.

SMP (based on MAFF, 1995)	Strategy (based on DEFRA, 2001)
hold the existing defence line	
advance the existing defence line	
retreat the existing defence line	managed realignment
do nothing	limited intervention
	no active intervention

Table 8.1 Comparison of policy definitions

For each unit, the preferred management policy will be identified, taking into consideration environmental, technical and economic constraints. As a first step in this process, the policy recommendations made in the Shoreline Management Plan will be reviewed and modified as seen to be appropriate.

Any particular management policy may be achieved in a number of ways. A number of alternative options are therefore identified where appropriate, with each one being assessed on its technical, environmental and economic merits, in order to identify the preferred option.

8.3 *Assessment of Present Situation*

Key features have been identified, together with specific environmental objectives for the frontage (full details are presented in Table 4.1 of the Strategic Environmental Assessment, Annex E).

At present there is limited intervention in terms of coastal defence for most of the Bay. For much of the Bay, the environmental value of the coastline lies in its natural eroding state, therefore it is likely that intervention will not be appropriate, unless there is key infrastructure of value.

Where defences exist, an assessment has been made of their condition and residual life as well as their sustainability during the strategy lifetime.

8.4 *Technical Assessment*

Having identified a preferred strategic policy for each management unit, alternative intervention options will be identified. A technical assessment of each of these intervention options will then be made. This will include, but not be limited to:

- impact of option on littoral drift;
- likely performance of option given local conditions;
- availability of raw materials;
- sustainability of option.

8.5 Environmental Assessment

Each of the various options will be assessed on the basis of the environmental objectives derived as part of the Strategic Environmental Assessment (see Chapter 7). For each unit, options will then be ranked by their acceptability in environmental terms.

It is not anticipated that any one option will meet all environmental objectives, as there are conflicts that arise within the objectives themselves, so an assessment will require to be made on which options are the least onerous in environmental terms.

8.6 Economic Assessment

Economic assessment of technically and environmentally acceptable options is completed in accordance with MAFF Project Appraisal Guidance (MAFF, 1999). The maps derived during the cliff behaviour assessment (see Chapter 4) were used to identify assets at risk under the "do nothing" scenario in order to assess the benefits of intervention options. These benefits might be delays in erosion or landslipping or, for the case of early warning systems, the benefits gained from early warning of the need to evacuate properties, allowing residents to remove possessions, thereby reducing the losses.

9 Detailed Strategy Development

9.1 *Knipe Point to Clifton Crag (Management Unit 24A)*

Figure 9.1 *North end of Cayton Bay – Tenant's Cliff and Cayton Cliff*

9.1.1 *Description*

The degraded coastal slopes in this unit are characterised by large scale relict landslides developed in Jurassic strata and overlying glacial tills. The unit is fronted by a sweeping sandy beach (Figure 9.1), with boulders present in places, remaining from previous landslides and subsequent erosion of the deposits. Landslides are common, creating a series of terraces and seepage ponds. The slopes are tree-covered between Knipe Point and Tenant's Cliff. At Tenant's Cliff, near-vertical cliffs form the seaward boundary of a relict landslide complex. These sea cliffs are formed from landslide debris and are protected to some extent by large boulders deposited on the beach as the coastline has receded. Groundwater is a major factor influencing the failure of the slopes, however wave-induced erosion also has an influence.

There are no man-made defences within the management unit. Above Cayton Cliff is the settlement of Osgodby and a residential / holiday development is located at Knipe Point. The A165 coast road runs along the cliff top, and is scheduled to be relocated landwards due, amongst other concerns, to coastal recession.

This unit has two environmental designations: SSSI and SINC. Other points of interest include archaeological finds and Second World War pillboxes, which have been identified as having a potential heritage value. The wooded coastal slopes are owned by the National Trust, who maintain the footpaths that provide access to the beach.

There are no formal tourism amenities within the unit, although the Bay is actively used by walkers and for surfing and windsurfing. The EA monitor water quality to check compliance with the EC Bathing Water Directive. The close proximity of caravans means that the beach is of value to the tourism generated.

The Cleveland Way runs through this unit and is particularly vulnerable to the effects of erosion / landslip. Options for this unit should ensure that this route is either maintained or relocated.

The proposed environmental objectives for this unit are:

Proposed Objectives (see Annex E)	
24.A.1	Maintain open sandy beach
24.A.2	Maintain pedestrian access to Cayton Cliff Woodlands
24.A.3	Maintain existing extent and quality of exposures of type localities of Tenants Cliff Member and type fauna of Buckowskii subzone (SSSI)
24.A.4	Facilitate conservation or, if lost to cliff erosion, the re-creation of freshwater pool on Tenant's Cliff supporting tubular water-dropwort & possible populations of great crested newt
24.A.5	Maintain bathing water quality to comply with EU directive mandatory level
24.A.6	Avoid disturbance to World War II defence system remains on beach
24.A.7	Protect cliff top property threatened by erosion and cliff slumping, if feasible, economic and sustainable
24.A.8	Maintain road infrastructure of A165 and proposed diversion
24.A.9	Maintain recreational value of beach

9.1.2 *Options*

The proposed policy in the SMP is to "retreat the existing defence line". This will have clear implications on the long-term sustainability of the properties at Knipe

Point, some of which are very close to the cliff edge, and it is likely that some of these properties will be lost within the strategy lifetime. It is recommended that this policy be revised to 'limited intervention' based on revised DEFRA guidance and clarified definitions. The future recession of the coastline is recognised in the plans for landward realignment of the A165, which runs along the cliff top. It is considered that intervention may be appropriate for Cayton Cliff, however that intervention is less appropriate for Tenant's Cliff given the proposals for relocation of the road, the limited number of properties on the cliff top, and the relict nature of the landslide. The debris lying on the beach provides some limited protection to the sea cliffs against wave erosion and the rate of recession of these cliffs is relatively low.

Options for Cayton Cliff are discussed below:

(a) Rapid response monitoring system

A rapid response monitoring system could be considered for assets at risk from landslip or ground movement. This may allow warning of ground movements within Cayton Bay that might lead to dangerous conditions or loss of property, by use of ground movement sensors, linked to a data logging and warning system. Management and operation of such a system should be carefully planned, in conjunction with an evacuation procedure for properties in the risk area. It is recommended that implementation of the warning system includes for interpretation of measurements by suitably qualified personnel to identify risk scenarios and prevent false alarms.

(b) Re-grading of coastal slopes

Regrading of the coastal slopes could assist in achieving a more stable slope, and therefore reduce the likelihood of landslips occurring. The vegetated nature of the slopes in this unit would however mean that this would have a significant environmental impact, and this would therefore not be a preferred option.

(c) Toe protection

Rock protection at the foot of the coastal slopes could provide protection against erosion of the toe that may induce slope instability. Given the large scale nature of the relict landslide, such toe protection would require to extend over a length of approximately 350m. Such an option might delay cliff recession but will not halt it completely. In the event of a large scale landslide event, it is likely that toe protection would be overwhelmed by the runout of landslide debris onto the beach (i.e. mudslide lobes).

(d) Improved drainage of coastal slopes

Improvements in drainage may be carried out to varying degrees of sophistication. At its simplest, this may comprise improvements in the surface drainage network, controlling run off from properties and paved areas. More sophisticated drainage solutions might include installation of vertical and horizontal drains within the coastal slopes to reduce ground water levels and improve stability.

Provision of drainage ditches for the coastal slopes at Cayton Cliff is recommended as an option. The ditches could be dug on the wooded coastal slopes to control groundwater and surface water. Ground movements are likely to continue so annual maintenance of the ditches should be undertaken to ensure that the ditches are kept in good repair and any blockages are removed.

(e) Policy for developed areas

It is clear that any options for this management unit will only control the impacts of cliff recession in the short term. Planning guidance is available for the control of development in the coastal zone. However it is clear that there are existing properties at risk at Knipe Point and Osgodby within the strategy lifetime, and policy regarding developed areas should therefore be confirmed. The cliff mapping exercise undertaken as part of the strategy has allowed a best estimate of cliff recession and therefore property losses within the strategy lifetime to be made, based on site observations. A more detailed slope stability study could be undertaken, including ground investigation to quantify more fully the risk to properties. This would produce objective guidance for planning, development and slope management for the area, and allow management of the evacuation of properties. Such an approach is supported by the DTLR and Planning Policy Guidance Note PPG14.

(f) Monitoring of beach and coastal slopes

In order to improve longer term understanding of the shoreline evolution, a programme of monitoring of beach levels should be continued, using the survey completed in 2000 as a baseline. Monitoring of beach levels and cliff recession rates will provide useful data for future modelling of behaviour. While this will not delay loss of property, it will help to quantify the rate at which the coastline is retreating and help with future management. Monitoring recommendations are discussed further in Section 11.2.

It should be noted that options (e) and (f) above are not intervention options in themselves, but activities that would support management of cliff recession and the associated risks to infrastructure.

9.1.3 *The Do-Nothing Scenario*

There is a degree of uncertainty regarding the 'do nothing' scenario for this management unit. The unit comprises 2 major landslide complexes: Cayton Cliff at the northern end and Tenant's Cliff at the southern end. The cliff behaviour assessment undertaken as part of the strategy study (documented in Annex D) has identified a number of potential landslide scenarios that might reasonably be expected to occur within the strategy lifetime for each of these units:

Cayton Cliff

- There is a high likelihood of small-scale failure of the rear scarp, causing localised settlement of cliff top land, within the strategy lifetime.
- Some risk of major reaction within the current boundaries of the landslide complex resulting in run-out of debris onto the beach.
- Initiation of major landsliding involving rapid loss of cliff top land. While there has been no recent failure of the rear and edge scarps, continued degradation has caused these to steepen and stability to decrease. There is therefore increasing potential for first time failure of these scarps in the future. While it is not possible to predict when such an event may occur, it is assumed that such an event is likely over the next 50 years, and that the probability of occurrence will increase with time. Rendel Geotechnics (1996) postulate that major landsliding of this nature can be expected every 100-250 years and is likely to be similar in form and mechanism to the Holbeck Hall landslide, which resulted in the rapid loss of 60m of cliff top land.

Tenant's Cliff

- The more likely scenario for the next 50 years is for continued erosion of the sea cliffs with relative inactivity within much of the relict landslide. Localised small-scale failures of the rear scarp, involving the loss of 2m or less of cliff top land may occur from time to time.

The landslide activity predicted within the unit would place cliff top properties at risk. Potential property losses within the strategy lifetime have been based on the cliff mapping presented in Annex D and the resulting upper bound of cliff recession potential. This identifies a risk to properties at Knipe Point and a risk of

loss of residential properties along the A165 coastal road, if the Tenant's Cliff landslide is reactivated, though this risk is assessed as being small, particularly within the early part of the strategy. It is likely that the A165 will be breached, although this is scheduled to be relocated further inland within the lifetime of the strategy, due to a number of issues including traffic management and the risk due to cliff recession. It is likely that the woodland owned by the National Trust will be lost as result of continued land movement.

9.1.4 *Selection of Preferred Option*

The identified options are summarised in Table 9.1. For each of these options, the Table summarises the technical, environmental and preliminary economic assessments made. Those options identified as being viable are considered in a more detailed economic assessment, summarised in Table 9.2.

The preferred option for this unit is identified as improved drainage of Cayton Cliff. This is likely to bring some improvement in slope stability, and provide (a limited) delay in cliff top recession, extending the life of the properties by an estimated 10 years. There is still a risk that this might occur within the strategy lifetime. Improved drainage of the cliff would aid stabilisation and consequently strengthen the cliff against erosion at the cliff toe from the sea.

The unprotected coastal cliffs of Tenant's Cliff comprising landslide debris should be left to continue to erode naturally. While there is some risk of ground movements leading to reactivation of the relict landslide, the nature of the landslide is so large scale that engineering approaches to prevent this cannot be justified.

Plans exist to relocate the A165 road that runs along the cliff top within the strategy lifetime, although the precise timing of this is not known. As a result the A165 has not been included in the economic assessment that has been undertaken as part of the strategy development.

It is recommended that the Highway Authority undertakes monitoring of the cliff position at pinch points in the vicinity of the road in the interim period before relocation to warn of any increased risk to the road. This may involve site inspections at regular intervals, or alternatively a more comprehensive early warning system may be put in place to warn of ground movements.

Should the Cleveland Way be threatened by coastal recession resulting in a risk to public safety on the cliff edge, or breaching of the Way, then this footpath should be relocated landwards. Where possible this should be through land that is in keeping with its current location.

In addition, it is recommended that monitoring of the slopes and the foreshore be undertaken to improve understanding of processes and identify any changes taking place.

Further details of the values and locations of assets at risk are described in the full Economic Assessment located in Annex F.

Cayton Cliff	Costs and benefits £k			
	Do nothing	Rapid response monitoring	Toe protection	Improvements to cliff drainage
PV costs	389.6	45.6	415.6	52.3
PV damage		350.7	162.6	217.6
PV benefits		39.0	227.1	172.1
NPV		-6.7	-188.5	119.8
Benefit/cost ratio		0.85	0.55	3.29
Incremental b/c ratio			0.51	0.15

Table 9.2 Cayton Cliff - Economic assessment of options

Option		Environmental	Technical	Economic	Conclusions
A	Early warning system	No adverse environmental impacts	Will provide advance warning of losses, providing appropriate thresholds set. Management will require careful consideration.	Some reduction in losses as provides opportunity for evacuation and removal of possessions, but will not prevent loss of properties.	Considered in economic assessment.
B	Re-grading of coastal slopes	Loss of important invertebrate species dependent on natural cliff slumps that colonise bare ground. Interference with geological exposures.	Not practical given vegetated nature of slopes.	Not considered further.	Not considered further.
C	Toe Protection	Aesthetic detraction to area; Interference with geological exposures/ possible vegetation of cliff face; Impact on invertebrate species dependent on cliff slumps.	Likely to be overwhelmed of large scale movement occurs.	Costs likely to outweigh benefits.	Considered in economic assessment.
D	Drainage improvements	Simple techniques proposed likely to have minimal impact. Method of working to ensure minimal impact during construction / maintenance.	Will provide some delay in cliff recession, using simple techniques.	Will provide some delay in losses and therefore reduce risk.	Considered in economic assessment.

Table 9.1 Summary of options appraisal – Cayton Cliff (management unit 24A)

Option		Environmental	Technical	Economic	Conclusions
E	Stability studies / planning policy guidance	No adverse environmental impacts	Will inform future strategy review.	Will help to control future development in risk areas.	Given limited development and low risk of large scale movement, not recommended. To be reconsidered at strategy reviews.
F	Monitoring	No adverse environmental impacts	Will help inform future strategy review.	No direct economic benefit.	To be recommended in conjunction with any intervention option.

Table 9.1 Summary of options appraisal – Cayton Cliff (management unit 24A) Cont'd

9.2 *Clifton Crag to High Red Cliff (Management Unit 24B)*

Figure 9.2 Central Cayton Bay - Killerby Cliff to Tenant's Cliff

9.2.1 *Description*

The unit is characterised by soft glacial till cliffs as in Unit 24A (Figure 9.2). Landslips are a feature of this section, due to a combination of groundwater and coastal erosion at the toe of the cliff, and there were recent slips (spring 2001) on the frontage of the Beach View Caravan Park.

This unit includes defences at the southern edge of Tenant's Cliff comprising a masonry and concrete seawall and apron, which protect a disused water pumping station and a single residential property beneath Tenant's Cliff. These defences are discussed in further detail in Section 6. There is a division of ownership of the defences and intervention will therefore require a unified approach between owners.

Steps over the defences provide access to the beach at this point, with a kiosk located at the top of the steps. There is significant damage to this section of the defences, with the concrete slab and apron being badly broken up in places. This presents a safety hazard to beach users, particularly given the close proximity to the beach access. SBC have undertaken interim repair works to repair this damage, however these defences are unlikely to be sustainable throughout the strategy

lifetime. Adjacent defences protecting the pumping station are in better repair and are therefore less likely to fail within the strategy lifetime.

Cliff erosion and landslips continue on the unprotected cliffs adjacent to the defences. There is potential for outflanking of the defences during the strategy lifetime. The transition between the hard defences and the cliffs will therefore require to be managed. Alternatively, future strategy reviews may identify that defences should be abandoned.

Along the top of the cliffs there are a number of residential properties, and a commercial surfing centre, forming the Killerby Cliffs community. The Beach View Caravan Park is also located on the cliff top. Cliff recession is occurring, and there is an isolated property at the seaward limit of Beach View caravan park at risk in the short term. There are problems of flooding and groundwater at Killerby Cliffs, which is likely to be contributing to cliff instability. Maps and aerial photographs indicate the presence of rock outcrops seaward of Killerby, resulting in a wider beach at this location, which is likely to provide some protection to the cliff toe.

Beach access is located here by means of a surfaced footpath down through a gully in the cliff. During the winter of 2000/2001, the footpath was blocked by landslips, and maintenance was subsequently undertaken by SBC to clear the footpath. It is recognised that clearance of the footpath will only provide a relatively short term solution to the problem, as the gully slopes are inherently unstable and further slips are likely to be triggered, during extreme wet conditions. A submarine cable also comes ashore at Killerby Cliff in the vicinity of the footpath.

The Cleveland Way runs through this unit and is particularly vulnerable to the effects of erosion / landslip. Options for this unit should ensure that this route is either maintained or relocated landward as the cliff recedes.

The unit holds SSSI and SINC environmental designations. World War II pillboxes are also present on the foreshore.

The proposed environmental objectives for this unit are:

Proposed Objectives (see Annex E)	
24.B.1	Maintain open sandy beach
24.B.2	Avoid interference with intertidal habitat and characteristic biotopes of Lebberston & Gristhorpe (SINC)
24.B.3	Create or maintain vegetated soft cliffs, allowing for landward migration as cliff recedes
24.B.4	Avoid interference with intertidal and subtidal sandy and rocky habitat
24.B.5	Protect cliff top property threatened by erosion and cliff slumping, if feasible, economic and sustainable
24.B.6	Maintain existing extent and quality of exposures of Callovian rocks and Gristhorpe Plant Beds (SSSI)
24.B.7	Maintain bathing water quality to comply with EU directive mandatory level
24.B.8	Maintain pedestrian access points to Killerby Cliff
24.B.9	Avoid disturbance to World War II defence system remains on beach
24.B.10	Maintain road infrastructure of A165 or proposed diversion
24.B.11	Maintain Cleveland Way footpath along Killerby Cliff
24.B.12	Maintain recreational value of beach

9.2.2 *Options*

The recommended management policy for this unit as proposed in the SMP is "Do nothing". The SMP also notes that this is the preferred centrally funded option and that the 'retreat the existing defence line' policy may require further consideration, subject to economic appraisal. It is recommended that the policy be revised to "limited intervention". Key interventions required will be management of beach access given the tourism value of the beach and management of the Cleveland Way, with realignment as required due to cliff recession. Landward relocation of the caravan park should also be considered as the coastline retreats. Options considered for this unit are:

(a) Improved cliff drainage at Killerby

Improvements in drainage may be carried out with the intention of controlling groundwater within the cliffs to varying degrees of sophistication. This may comprise improvements in the surface drainage network, controlling run off from agricultural land, properties and paved areas, and continued maintenance of existing drainage ditches. Provision of a cut off surface drain landward of the bund to the rear of the properties may help to delay cliff recession by collecting and draining water which may otherwise lead to erosion. Improved drainage would help to stabilise the cliffs and therefore make them more resilient to coastal erosion at the cliff toe.

(b) Maintenance of footpath at Killerby

The footpath at Killerby is located in a gully with very steep side slopes. It is likely that landslips, such as occurred during the winter of 2000-2001, blocking the path will reoccur. Routine maintenance should therefore allow for periodic re-grading of these slopes.

A more permanent alternative solution would be to regrade the gully slopes to a more stable angle, and therefore mitigate the risk of further landslip. Control of surface water drainage and groundwater as discussed in (a) above would also help mitigate further landslip.

(c) Removal of existing defences at Tenant's Cliff

The existing concrete defences form a strong point within a naturally receding coastline. The defences at the southern end, adjacent to the beach access are in poor repair and have a low residual life. It is recommended that these defences be removed as they reach the end of their useful life, particularly as this may result in a safety hazard for beach visitors. The defences are located at one of the key beach access points and it will be important to maintain this access, given the tourism value of the beach. Replacement of the hard defences with more flexible solutions will allow management of beach access as the coastline retreats. A typical approach might be grading of the lower slope beneath the access road and placement of geogrids or a similar product to provide pedestrian access with erosion control.

The northern seawall defence which protects the pumping station and house at Tenant's Cliff is in better repair and at this stage in the strategy it is not considered that this need be replaced. It is possible that natural processes will result in outflanking of these defences in the later stages of the strategy lifetime and this condition of the defence should therefore be reassessed at strategy reviews. The cliff behaviour assessment identified that there is a low likelihood of large scale movement of the relict landslide behind these defences, however this risk does exist and in the event of such movements the defences may fail and the protected properties may be lost.

(d) Policy for developed areas

None of the intervention options for this unit will completely prevent coastal cliff recession. Accordingly, further development in the area is controlled by planning policy for the coastal zone. However it is clear that existing properties are likely to be at risk within the strategy, at Beach View, Killerby Cliffs and the single property

at the foot of Tenant's Cliff. SBC should therefore confirm policy for these areas within the strategy lifetime and beyond. The cliff mapping exercise undertaken as part of the strategy allowed a best estimate of cliff recession and therefore property losses within the strategy lifetime to be made, based on site observations. A more detailed slope stability study could be undertaken, including ground investigation to quantify more fully the risk to properties. This would produce objective guidance for planning, development and slope management for the area, and allow management of the evacuation of properties. Such an approach is supported by the DETR and Planning Policy Guidance Note PPG14.

(e) Monitoring of beach and coastal slopes

In order to improve longer term understanding of the shoreline evolution, a programme of monitoring of beach levels should be continued, using the survey completed in 2000 as a baseline. This will provide useful data for future modelling of behaviour. While this will not delay loss of property, it will help to quantify the rate at which the coastline is retreating and help with future management. Monitoring recommendations are discussed further in Volume I.

Options (d) and (e) above are not specific management options in their own right but will assist in informing future strategy reviews and development proposals within the area.

9.2.3 *The Do-Nothing Scenario*

The do nothing scenario for this unit will result in continued cliff recession. This is likely to result in outflanking of the hard defences at Tenant's Cliff, and the condition of the defences will deteriorate. Properties are at risk within the management unit. Those properties located at Killerby Cliff may be at risk within the latter part of the strategy lifetime. The property at the seaward limit of Beach View Caravan Park is at risk within the early part of the strategy and the house and disused pumping station may be lost within the strategy lifetime.

9.2.4 *Selection of Preferred Option*

The identified options are summarised in Table 9.3. For each of these options, the Table summarises the technical, environmental and preliminary economic assessments made. Those options identified as being viable are considered in more detailed economic assessments, summarised in Tables 9.4 and 9.5.

A number of interventions are recommended within this unit.

As the existing defences at Tenant's Cliff deteriorate these should be managed, ideally being removed as they become unsafe. It is anticipated that the defences at the southern end adjacent to the beach access will require replacement within the first 15 years of the strategy. Alternative access will be required to replace these hard defences and it is recommended that this be done using soft engineering techniques (assumed to be Geogrids or similar) that can be managed to provide an access route as recession continues. The need to replace the defences protecting the pumping station should be reassessed at strategy reviews.

There is clearly an issue of continued access at Killerby Cliff, given the landslips that have blocked the footpath and the likelihood that this will continue to occur in the future. It is recommended that regrading of the gully slopes to is undertaken to improve stability.

Tenant's Cliff	Costs and benefits £k	
	Do Nothing	Provision of alternative beach access
PV costs	140.73	22.9
PV damage		58.5
PV benefits		82.2
NPV		59.3
Benefit/cost ratio		3.59
Incremental b/c ratio		

Table 9.4 Economic assessment of options – Tenants Cliff

Killerby Cliff	Costs and benefits £k	
	Do Nothing	Improvement to cliff drainage
PV costs	135.0	18.0
PV damage		75.4
PV benefits		59.6
NPV		41.6
Benefit/cost ratio		3.31
Incremental b/c ratio		

Table 9.5 Economic assessment of options – Killerby Cliff

Option		Environmental	Technical	Economic	Conclusions
A	Improved drainage at Killerby Cliff	Limited environmental impact anticipated as drainage improvements will be localised.	Will provide some delay in cliff recession using simple methods and will help prevent flooding.	Will provide some delay in losses.	Considered in economic assessment.
B	Re-grading of ravine slopes adjacent to footpath.	Some localised loss of important invertebrate species dependent on natural cliff slumps that colonise bare ground and interference with geological exposures, however given the localised nature of the proposed works and the frequent maintenance currently undertaken, this is not expected to be significant.	Likely to be undertaken from cliff top; no significant technical difficulties anticipated	Relatively low investment – will ensure continued access to beach and therefore amenity value to local economy	Recommended to ensure continued beach access.
C	Removal/ replacement of defences	Land behind defences already significantly modified therefore any geological exposures probably already affected. Short term impacts during construction.	Will ensure removal of structures that may become unsafe and maintain public access.	Will ensure continued amenity value of beach by maintaining access.	Considered in economic assessment.
D	Planning policy development	No adverse environmental impacts.	Will inform future strategy review.	Will help to control future development in risk areas.	Given low level of development, not recommended. To be reconsidered at strategy reviews.
E	Monitoring	No adverse environmental impacts.	Will help inform future strategy review.	No direct economic benefit.	To be recommended in conjunction with any intervention option.

Table 9.3 Summary of options appraisal - Clifton Crag to High Red Cliff (management unit 24B)

10 Recommendations & Conclusions

10.1 *Policy and Implementation*

The recommended strategy for Cayton Bay has been developed through considering individual frontage requirements and constraints, together with consideration of the influences on other management units and on the Bay as a whole and of the interdependencies between frontages. The proposed strategy is summarised in Table 10.1. Each management unit has been discussed in detail in Section 9.

Where possible, the recommendations made are for the lifetime of the strategy. In some areas, however, the long-term strategy might be modified to reflect changing circumstances, which cannot be fully identified at this stage, or issues that will not arise for some decades. Where issues are expected to arise at a later date, these have been highlighted and considered in the assessments made at this stage. It will be prudent to revisit these issues at Strategy reviews in the light of any new information.

The strategy time frame has been set at 50 years, consistent with DEFRA guidance. It is recognised that conclusions drawn today may be modified in the future given new information and changes in local or national government policy. Therefore, the strategy should be reviewed at least every five years and updated as necessary.

Actions for implementing this strategy are described in Chapter 11.

Management unit		SMP preferred management policy	Revised strategy management policy	Preferred option	Strategy review
24A	Knipe Point to Clifton Crag	Retreat the Line	Limited intervention	Improved drainage of Cayton Cliff	5 years
24B	Clifton Crag to High Red Cliff	Do nothing	Limited intervention	Improved drainage at Killerby Cliff; Removal of hard defences at Tenant's cliff; continued management of beach access.	5 years

Table 10.1 Summary of proposed strategy options

10.2 *Compliance with Shoreline Management Plan*

Generic coastal defence policies for the whole of this shoreline were established in the Shoreline Management Plan. This strategy has sought to confirm the appropriateness of these policies and to identify measures necessary to implement them. Recommendations have been made for changes to the proposed policies where this is deemed to be necessary. These changes are generally based on revised policy definitions given in DEFRA guidance, following production of the SMPs.

10.3 *Strategy Implementation and Associated Impacts*

10.3.1 *Built Environment*

The strategy fulfils the objective of protecting property where environmentally sustainable, feasible and economic. An estimate of the number of properties predicted to be at risk of loss to erosion and coastal retreat during the fifty years of the strategy is given in Table 10.2. It is anticipated that the majority of these losses will be likely to occur in the latter part of the strategy. The estimated losses at Osgodby and Knipe Point are dependent on reactivation of the Cayton Cliff landslide, which is considered to have a low likelihood within the strategy lifetime, although the risk remains.

Future planning guidance for the study area is summarised in Table 4.5 with further visual guidance provided in a series of maps C.1 and C.2 in Annex D.

Location	Residential Properties	Other Properties and land
Killerby Cliff	6	Car park,
Beach View	1	caravan park land
Tenants Cliff	1	Disused pumping station
Knipe Point / Osgodby (including Clifton Crag)	20-40	National Trust woodland and grazing land

Table 10.2 Estimates of potential losses of property under proposed strategy implementation

10.3.2 *Water and Aquatic Environment*

The strategy will have no long-term effects on the aquatic environment, although some minimal short term effects may result during strategy implementation if any materials need to be brought ashore by barge, however this is unlikely.

Achieving the objectives of maintaining or improving bathing water quality is outside the remit of the coastal defence strategy.

10.3.3 *Ecology and Nature Conservation*

The interventions proposed by the strategy have no significant adverse effects on nature conservation. Furthermore, no significant adverse effects on designated biological or geological interest features of the statutory protected (SSSI) and locally protected (SINC) areas are predicted from the proposed policies of limited intervention and retreat the line. There will be some loss of the existing nature conservation interests on the retreating soft cliffs and cliff tops as a result of natural processes of cliff erosion and retreat. This is accepted by the strategy as there are no technically feasible and sustainable interventions that would avoid the losses. Even if it were technically possible to arrest the process of cliff erosion, the nature conservation interest of the soft cliffs would be radically altered as the slumping process is integral to their ecology.

It is recommended that mitigation measures should be undertaken to re-create vegetated cliff-top and cliff-face habitats, including freshwater pools, lost to erosion will provide some benefits to nature conservation. Should it be required to inoculate 'replacement habitats' as part of habitat creation helping to safeguard the existing nationally important resource, collection of locally provenant stock or seed should be undertaken from SSSIs and SINC grassland sites and grown on for future inoculation purposes.

In general, maintaining natural processes and managing the process of retreat through cliff stabilisation will contribute to the sustainable conservation of wildlife habitats and species characteristic of this Natural Area. However, there will be a need for proactive policies to enable habitat setback to occur, since otherwise cliff-top and cliff-face habitats will become squeezed between the retreating cliff line and existing land uses on the cliff top such as caravan parks, residential properties and agriculture. It is recommended that setback be implemented through:

(a) land acquisition in the set-back zone by nature conservation bodies, including local authorities and the Yorkshire Wildlife Trust (It should be noted that some areas of land in the setback zone are already in Local Authority / National Trust ownership);

(b) bringing agricultural land under more sympathetic conservation management through stewardship funding or similar initiatives (this does not include land owned by the National Trust); and

(c) adoption and implementation of appropriate planning policies by local planning authorities, including the prohibition of any new building or extensions to existing buildings, for land in the set-back zone and exploration of possibilities to relocate the caravan park further inland.

10.3.4 *Landscape*

The proposed interventions will have no significant adverse effects on landscape. Proposed works to replace existing defences at the base of Tenant's Cliff which are in a poor state of disrepair will enhance the aesthetic appeal of the area and improve the safety of the defences which currently present a hazard to beach users, particularly given the close proximity to beach access points. The flexible nature of the proposed system will also enable relocation as the coastline recedes thus preventing outflanking which could otherwise alter the landscape of the bay.

Where no coastal defence interventions are proposed, the mitigation recommended by the strategy will provide some benefits to visual amenity on the retreating soft cliffs and cliff tops, compared to doing nothing. The character of significant landscape elements of the bay which is presently being submitted for Heritage Coast status will be maintained by the recommended policies of limited intervention and retreat the line. However, the process of erosion will bring existing development such as houses and caravan parks closer to the cliff edge at Killerby and Knipe Point before they are eventually lost. This will result in increased prominence of intrusive landscape features along the cliff top and shoreline. Mitigating this impact will be difficult as there are no established powers that can require structures to be removed because of their landscape impacts, in advance of erosion making them unsafe. However, should opportunities arise to negotiate large-scale removal and relocation of existing facilities such as caravan parks to more sustainable and less visually intrusive locations, rather than waiting for piecemeal loss at the cliff top, it is recommended that the Local Authority should pursue them. Opportunities to screen existing or new sites with tree planting should also be followed up where possible.

10.3.5 *Agriculture*

The impacts of the strategy on agriculture will be minor as there is limited agricultural land within the study area. There will be some small direct losses of grazing land owned and managed by the National Trust. The strategy recommends that areas of agricultural land be acquired on the open market and/or brought into conservation management to offset losses to cliff recession.

10.3.6 *Tourism and Recreation*

Adverse effects on tourism and recreation will arise from the partial loss of the following assets:

- Part of the Beach View caravan park
- Kiosk at Tenant's Cliff
- Cleveland way – to be relocated
- Beach access and/or parts of the car parking area

There will be a recreational benefit from the strategy recommendations to re-route the Cleveland Way footpath that will otherwise be lost to erosion. This responsibility should be shared between North Yorkshire County Council (as footpaths authority) and Scarborough Borough Council (as coastal protection authority). Intervention to re-route footpaths at Cayton Cliff is at the discretion of the National Trust who are the landowner of this section of the Bay. The timing of footpath relocation will be determined through cliff top recession monitoring (section 11.2).

Where limited intervention is planned this has been designed to avoid deterioration in the quality of beaches in the study area. Implementation of the strategy recommendations to replace the degraded concrete seawall and apron at the base of Tenant's Cliff (which form a strong point in the naturally receding Bay) with a flexible solution allowing management of beach access as the coastline retreats would, if carried out during the summer months block public access to the beach at this point, and requiring the use of heavy machinery on the beach thus having an adverse effect on tourism and recreation. It is therefore recommended that this work be carried out in the autumn or winter, and that the peak holiday months should be avoided.

10.3.7 *Fisheries*

The strategy will not have any impacts on fisheries within the study area as there are no boat launching facilities within the bay. It is also unlikely that there will be any need for barge deliveries of material that could have a short term impact on inshore fisheries (including long-lining, trawling, nets and pots).

If barge deliveries are required for any materials due to the steepness of the access road at Tenants Cliff, mitigation in the form of seasonal control of the working period would not necessarily enable any impacts to be avoided altogether as fishing effort is all year round. However, details of controls, such as barge access routes

and delivery points, could be agreed with local fishermen when the requirements for any materials are determined.

10.3.8 *Transport Network and Traffic*

The interventions proposed by the strategy will have no significant effects on the transport network and traffic if the proposed landward relocation of the A165 coast road is implemented. While the present cliff top route remains in use, the risk of breaching of the road due to ground movements exists. This risk is determined by the probability of the reactivation of the Cayton Cliff landslide complex. It is not possible to predict when such a major landslide event may occur as little is known of the stress regime, however there is a likelihood that this may occur within the lifetime of the strategy and this likelihood will increase with time.

10.3.9 *Cultural Heritage*

The strategy provides for the protection of the archaeological assets within the Bay. Based on estimated cliff recession potential, no known archaeological sites at risk of loss within the strategy lifetime.

There are no Scheduled Monuments within the Bay and therefore the most significant sites liable to loss are parts of the WWII defence structure complex that could be liable to damage through cliff slumping. Excavation and recording is proposed to mitigate the loss of any sites expected to be lost within the lifetime of the strategy.

Mitigation in respect of sites expected to be lost to erosion should be commissioned and co-ordinated by the archaeological unit of North Yorkshire County Council. It is not anticipated that any known archaeological sites will be adversely affected by coastal defence/stabilisation interventions. If, however, a need for archaeological mitigation were identified during the development of specific schemes, this would be the responsibility of the coastal defence operating authority commissioning the works.

10.3.10 *Air Quality*

The strategy will have no significant effects on the atmospheric environment. The potential for construction works to release dust will be limited by the damp nature of materials in the intertidal zone, and it is not expected that any specific mitigation measures would be needed over and above normal good working practice.

10.4 Strategy Economics

10.4.1 Summary of Economic Assessments

The recommended strategy as presented in Table 10.1 has been considered in economic terms as part of the assessment process (presented in Annex F and summarised for each management unit in Section 9). This assessment is summarised in Table 10.3 for those units where intervention is required. The economic assessment follows guidance produced by the Department of Environment, Food and Rural Affairs (DEFRA), and considers all expenditure over the strategy timeframe, discounted to present value (PV) to take account of the timing of expenditure. The benefit cost ratio (BCR) is a simple measure of the economic worth of the scheme.

Management unit	Option	PV Costs (£k)	PV Benefits (£k)	Benefit Cost Ratio
24A -Knipe Point to Clifton Crag (at Cayton Cliff)	Early warning system	45.6	39.0	0.85
	Toe protection	415.6	227.1	0.55
	Improvements to cliff drainage	52.3	172.1	3.29
24B - Clifton Crag to High Red Cliff (at Tenant's Cliff)	Provision of alternative beach access	22.9	82.2	3.59
24B - Clifton Crag to High Red Cliff (at Killerby Cliff)	Improvements to cliff drainage	18.0	59.6	3.31

Table 10.3 Summary of economic assessment

10.5 Risk and Sensitivity Assessment

Sensitivity and risk play an important part in determining the preferred strategy. When undertaking works or operating schemes in the future it is important that the risks are identified and appropriate actions are taken. A key requirement to ensure control of risks will be ongoing monitoring for the study area in order to assist in future strategy reviews. Where works are proposed, early consultation with relevant parties will be important to reduce the likelihood of objections to schemes at a later date.

To ensure that the strategy recommendations made are "robust", the sensitivity to change of certain factors has been considered in the strategy development. The

following sections highlight particular concerns under headings of relevance to strategic planning adopted from the DEFRA guidance given in FCDPAG4 'Approaches to Risk' (MAFF, 2000).

Potential risks have been identified and addressed as far as possible in the development of the strategy. These risks will, however, remain primary considerations as the strategy and individual schemes are progressed in the future. Actions to assist in reducing risks include continual improvement in knowledge, such as ongoing monitoring for the study area. Where other actions are deemed necessary to assist in controlling risks, these are identified below and are summarised in Table 10.4.

10.5.1 *Poor definition of the extent of the problem*

Clearly one of the key factors in determining the timing of intervention works within Cayton Bay is the rate of coastal recession. Field observations and interpretation of historic maps have allowed assessments of recession rates to be made throughout the Bay. Understanding of this recession will be improved by continued monitoring which will allow predictions to be updated as necessary.

10.5.2 *Lack of knowledge or appreciation of processes*

An understanding of processes within Cayton Bay has been developed based on previous studies and on modelling. In order to improve this understanding a number of recommendations are made as part of the strategy. Firstly, it is recommended that a comprehensive monitoring programme be undertaken, which will allow continual improvement in understanding of processes. In addition, a more detailed hydrodynamic study of Cayton Bay is recommended to further improve this understanding, and in particular develop further understanding of offshore movements of sediment. This may be undertaken in conjunction with the study proposed in the strategy study for Filey Bay.

10.5.3 *Uncertainties about the performance of existing and proposed defences*

The only defences that are considered in the strategy are at Tenant's Cliff. An assessment of defence performance has been based on site inspection and the CPSE data. While there may be some uncertainty regarding the residual life of these defences, it is recognised that the defences are likely to be removed within the strategy lifetime. If the residual life is over-estimated, then these works will require to be brought forward.

10.5.4 *Interaction between different schemes & multiple failures*

Factors considered here include the timing and phasing of works and availability of funding. These can affect works going ahead, which in some cases may have a major affect on adjacent frontages. Given the limited nature of the proposed intervention works it is not anticipated that there will be any adverse interaction between different areas of the frontage.

10.5.5 *The economic evaluation of damages*

The degree of detail in which damages have been assessed is more than adequate for a strategic level of analysis. At a more detailed stage, for example a Feasibility Study or Engineer's Report, it is likely (and usual) that additional benefits would be recognised, increasing benefit values.

However, it is also possible that at detailed design stage of any schemes, unforeseen problems may be identified which may increase costs. Equally, changes in market forces may mean certain materials or operations become more expensive. The possibility of increases in costs has been assessed during the economic assessment, by testing the preferred options to ascertain what magnitude of increase in cost would make the scheme economically unjustified.

10.5.6 *Large-scale impacts on natural processes*

It is not considered that intervention works proposed will have any adverse large-scale impacts on processes. This may be further assessed by means of the hydrodynamic studies recommended as part of the strategy.

10.5.7 *Variations in Future Storm Frequency & Direction*

The preferred strategy has been informed by modelling undertaken to establish sediment transport processes. This modelling was driven by wave data derived from the Met Office wave model, with some sensitivity testing of the influence of wave direction.

10.5.8 *Timing of Expenditure*

Many influencing factors exist which could lead to delays in implementation and these are discussed above. Recommended intervention times are seen as the approximately correct time for action. Where uncertainty exists regarding the necessity of schemes, monitoring is proposed to inform strategy reviews. Should the monitoring reveal less dramatic changes in processes/foreshore levels than predicted from the current study, then there may be capacity to delay expenditure.

Alternatively monitoring may recommend a more urgent requirement for intervention works.

10.5.9 *Variation in Costs*

The costs of works have been derived based on current prices taken from a range of projects and from typical cost rates provided by SBC. These costs may increase, the extent of works may be underestimated (or unforeseen problems could arise), equally, availability of materials could become more scarce in the future. Instead of attempting to pre-empt any market changes or design details to estimate any increase in applied costs, a reverse process has been undertaken to evaluate by what percentage costs would have to increase to drastically alter the economic justification of the preferred strategy. The threshold of justification was assumed to be a benefit cost ratio of 3 (the median value of funded schemes in 1998).

Strategy risk identification	Probability (H/M/L)	Consequence (H/M/L)	Mitigation measures (to be) undertaken	Action by
Poor definition of extent of problem	L	M	Review of strategy at 5-year intervals	SBC
Lack of knowledge of processes	M	M	More detailed hydrodynamic studies are recommended to inform strategy reviews	SBC
Uncertainties of defence performance	M	L	Limited information on structures. Condition to be monitored. Strategy recommends that defences may not be sustainable, particularly those at southern end in SBC's ownership as these are in poor repair.	SBC / Defence owners
Interaction between different schemes	L	L	Limited intervention options proposed at discrete locations; interactions not anticipated	Addressed in strategy
Economic evaluation of damages	L	M	Assessment made a high level appropriate to strategy; more detailed studies likely to yield higher benefits, improving economic justification	Addressed in strategy
Large scale impact on natural processes	L	L	Limited intervention so significant impact not likely	Addressed in strategy
Variations in storm frequency / direction	M	M	Monitoring of beach response and wave / water level data collection	SBC
Timing of expenditure	M	M	Sensitivity testing of economic assessment to establish scope for variation	Addressed in strategy
Variation in costs	M	M	Sensitivity testing of economic assessment to establish scope for variation	Addressed in strategy

Table 10.4 Risk Register

10.6 *Opportunities arising from the Strategy*

10.6.1 *Joint Initiatives*

Key opportunities arising from the strategy relate to the need for co-operation between different land owners. There is scope for co-ordination of the management of the defences at Tenant's Cliff. As sections of these defences become redundant and are removed, the transition will require careful consideration.

Recommendations for management of Cayton Cliff are made, with the intention of prolonging the lifetime of the cliff top properties. As this land is under National Trust (NT) ownership, there will be a need for liaison with NT to ensure implementation of the strategy recommendations.

Management of the cliff recession will be most effectively carried out in close liaison with the local residents. There will be clear advantages in involving the local community in strategy implementation.

10.6.2 *Natural Environment*

It has been identified that there are opportunities for recreation of vegetated cliff-top and cliff-face habitats, including freshwater pools, to replace those lost to erosion. There will be a need for proactive policies to ensure this habitat recreation and avoid squeezing of habitats between the receding cliff line and the boundaries of holiday parks and other developed areas. This may be achieved by land acquisition in the set-back zone by nature conservation bodies, more sympathetic management of agricultural land and adoption and implementation of appropriate planning policies. Seed collection should also be undertaken from the SSSIs and grasslands sites and grown on for future inoculation of replacement habitats.

10.7 *Further Investigation*

10.7.1 *Studies and Research*

Through the development of the Strategy, a need for further investigation on certain issues has become apparent. These generally arise in areas where some uncertainty remains surrounding future trends in processes, the justification of potential schemes, or conflicts of environmental objectives.

Key initiatives recommended to address these issues and increase the resolution of the Strategy are:

- Complete hydrodynamic modelling study in conjunction with Filey Bay to improve understanding of coastal processes;
- Future review and updating of process understanding from monitoring data;
- Extension of strategy to encompass management unit between the south end of Cayton Bay and Filey Brigg.

10.7.2 *Monitoring*

Recommendations for future monitoring form a key part of the strategy. The main findings relating to quality of monitoring data are presented here with suggestions for considerations when reviewing current practices.

(a) Topography and bathymetry

As part of the strategy study, a bathymetric and topographic survey was undertaken. This will serves as a baseline for future surveys to be implemented during the strategy lifetime. This survey included beach profiles at key locations. It is recommended that additional beach profiles be recorded throughout the bay at higher resolution as identified in the SMP. As part of the survey, permanent markers were located on the cliff top to allow measurement of cliff position and further quantification of recession rates. Full recommendations for monitoring including frequencies and spatial resolution are given in Chapter 11.

(b) Waves and water levels

Wave data used in the modelling study was taken from the UK Met Office Northern European Wave model. Offshore wave conditions were obtained at a selected point and transformed to inshore points using mathematical modelling. This data is generally well controlled by the Met Office's own quality assurance procedures.

Recommendations were made in the SMP for deployment of a wave rider buoy and a tide gauge at either Whitby or Scarborough. These recommendations should be implemented to benefit both this strategy and those strategies for adjacent frontages. This recommendation has also been made as part of the Filey Bay Strategy Study and will clearly benefit the future development of both of these strategies as well as those for other adjacent management units within the Council's remit.

(c) Habitat Survey and Seed Collection

No recent surveys have been undertaken of the main habitat types within the Bay, notably species rich grassland, semi-natural woodland, springs, open pools and bare ground, intertidal boulders and wave cut platform. Existing Sites of Importance to Nature Conservation (SINCs) cover the southern extremities of Cayton Bay that were surveyed in 1998, however the SINC Panel has recently agreed that the coastal cliffs and other maritime habitats in the Bay are sufficiently important to warrant at least designation as a SINC along the full length of the coastline excepting the settlement areas. Existing national designations (SSSIs) within the study area preclude the need for further SINC designations within this area. A national inventory of maritime cliff and slope vegetation is also being prepared by English Nature. It is recommended that liaison with English Nature, the Scarborough Borough Council ecologist, County Ecologist and the National Trust is undertaken to progress:

- a comprehensive habitat / species survey of the bay
- seed collection for inoculation of replacement habitats

The survey will provide important data for the maritime cliff and slope inventory operated by English Nature and for land owned by the National Trust, enabling informed sustainable management of their land as the previous biological evaluation and associated management suggestions for this land was last undertaken in 1987.

11 Implementation Plan

11.1 *Recommended Programme of Work*

A schedule of recommended activities is given in Table 11.1. Key activities that require to be implemented are the recommended drainage improvements at Killerby Cliff and Cayton Cliff. These improvements will assist in delaying cliff recession and prolong asset life.

As properties are identified as being at risk, it is recommended that a contingency plan is developed and put in place for management of this risk and the potential losses.

Recommendations are made for management of beach access to ensure the continued amenity value of the Bay throughout the strategy lifetime.

Monitoring recommendations are made which form part of SBC's strategic monitoring programme. It is also recommended that the Highway Authority implements a programme of monitoring, possibly comprising an early warning system, to identify any increased risk to the A165 in the interim period before its diversion.

Recommendations for funding of the proposed activities are included in Table 11.1.

11.2 *Monitoring Requirements*

Monitoring of coastal processes and defence condition will provide a key source of information for use in future refinements of the strategy for Cayton Bay. In order to make the most effective use of this information, it is recommended that it be stored in a database that allows easy interrogation and access to the data. SBC operate their own PC-based 'Keyshore' database and it is anticipated that this system will be used for data management, to ensure ease of retrieval for future studies / analysis, ensuring the most effective use of data collected during the strategy time frame.

The Shoreline Management Plan gives monitoring recommendations for the full extent of sub-cell 1d (Huntcliffe to Flamborough Head), under the following headings:

- Aerial photography
- Bathymetric survey
- Offshore wave climate
- Wind records
- Water levels
- Beach profile surveys
- Defence condition survey
- Cliff top erosion monitoring
- Visual observation

The recommendations given in the SMP are considered in more detail in the following sub-sections, with additional recommendations made where identified as necessary. The scope of monitoring identified in the SMP forms the basis of a regime that will allow the collection of substantial baseline data on hydrodynamic conditions, shoreline evolution and cliff recession, allowing assessment of rates of change and identification of trends in processes.

Monitoring data should be reviewed at five year intervals to inform the recommended five yearly strategy reviews.

Description (section references are those in Strategy report)	Responsibility (funding)	year	NPV Total	Expenditure / year (£)							
				1	2	3	4	5	6-10	11-20	21-50
			PV factor	1.00	0.94	0.89	0.84	0.79	0.68	0.44	0.14
Schemes											
Cayton Cliff drainage	SBC (DEFRA)	1-5	48,628		23,100	1,850	1,850	1,850	9,250	18,500	55,500
Simple drainage measures to control surface / ground water											
Killerby Cliffs drainage	SBC (DEFRA)	1-5	21,109		7,000	1,000	1,000	1,000	5,000	10,000	30,000
Provison of cut off drain adjacent to properties											
Killerby Cliff beach access	SBC	1	50,000	50,000							
Reprofiling of gully slopes (or alternatively continued maintenance)											
Removal of Tenant's Cliff non-sustainable defences under SBC ownership; provision of alternative beach access	SBC (DEFRA)	11-20	24,462							52,500	9,000
Defences to be removed as required due to cliff recession / increased risk to public safety											
Studies											
Extension of strategy	SBC (DEFRA)	1-5	18,868		20,000						
Extension of strategy to include section of coastline between High Red Cliff and Filey Brigg (where Filey Bay strategy commences)											
Hydrodynamic modelling (see Section 11.3)	SBC (DEFRA)	1-5	14,151		15,000						
Development of detailed hydrodynamic model for Filey Bay (most likely extended to include Cayton Bay) to improve understanding of sediment movements											
Development of action plan for risk areas	SBC	1-5	9,717	5,000	5,000						
To develop contingency plans											
Monitoring											
Strategic monitoring	SBC (DEFRA)	Included in SBC's strategic monitoring programme									
To be undertaken as part of SBC's strategic monitoring programme - detailed in Table 11.2											
A165 Highway Monitoring	Highways Authority	1-2	36,889	30,000	1,000	1,000	1,000	1,000	5,000		
Installation of early warning system recommended to warn of increased risk to A165 in interim period before relocation											
Monitoring review	SBC	5 yr intervals	12,756					4,000	4,000	8,000	24,000
Review of cliff and beach monitoring data to identify any key changes, to be undertaken at 5 year intervals to inform strategy reviews											
		Total	**236,579**	**85,000**	**71,100**	**3,850**	**3,850**	**7,850**	**23,250**	**89,000**	**118,500**

Table 11.1 Recommended programme of works

11.2.1 *Aerial Photography*

Comprehensive vertical and oblique aerial photograph records exist for the Bay. The vertical photography was taken in October 1999. Oblique photographs are available from 1984 and from the Futurecoast project.

A recent study undertaken on behalf of SBC has considered the use of aerial photography in future monitoring and management. The findings from this study will indicate the potential value of aerial photography for monitoring within the Bay.

11.2.2 *Bathymetric Survey*

On the recommendation of the SMP, and as part of this commission, a bathymetric survey was undertaken in November 2000, covering the extent of Cayton Bay. It is recommended that this be repeated on a 5 yearly basis.

11.2.3 *Offshore Wave Climate*

Information on the offshore wave climate was derived from the Met Office Wave model, for use in the modelling studies undertaken as part of the strategy. There is limited measured information on waves for the area. The SMP recommends the deployment of 1 or 2 directional wave rider buoys for the whole SMP area, in suitable offshore locations. It is clear that such a deployment will benefit future studies for Cayton Bay, and adjacent frontages. This should be undertaken as soon as possible, and it is recommended that the deployment be for a minimum of 5 years.

11.2.4 *Wind Records*

The SMP recommends that a digital wind recording station be established, at an exposed coastal location. Wind records are generally considered to be the most reliable source of long term meteorological information and can be used for the derivation of a wave climate for the area. It is recommended that this installation be undertaken to inform not only the Cayton strategy, but also strategies for adjacent frontages.

11.2.5 *Water levels*

Water levels used in the development of the strategy study were derived from the Admiralty Tide Tables. There is limited information on extreme water levels as no long term water level records are available for the area.

A 'Class A' tide gauge is located at Whitby with records from 1980. This data can be obtained from POL. It would appear that this information was overlooked at the time of the SMP as the recommendation was made that a tide gauge be located at either Whitby or Scarborough. There would of course be benefits in installing an additional tide gauge at Scarborough, as this is closer to the strategy area, and this should be considered subject to availability of resources.

11.2.6 *Beach Profile Surveys*

As part of the study, beach profiles were taken over the full length of the Bay at approximately 500m intervals. Permanent ground markers were set up that will facilitate repeat surveys. It is recommended that repeat surveys are undertaken twice a year, preferably post-summer to identify scope for build-up of the beach and post-winter to establish the effect of winter storms in lowering beach levels.

11.2.7 *Defence Condition Survey*

Periodic visual inspection and topographic survey of the defence structures in the Bay should be undertaken. It is recommended that this is undertaken on an annual basis. Reference should be made to the data contained in the CPSE records for the frontage (as summarised in Chapter 6) which refers to each of the structure elements, and this should be updated as appropriate. This will also help to inform when defences are likely to fail and require removal, as continued maintenance of defences is not considered to be sustainable during the strategy lifetime.

11.2.8 *Cliff Top Recession Monitoring*

Cliff top recession monitoring will allow estimates of cliff recession rates to be refined at a later date, based on actual measurements. As part of the survey work undertaken for the strategy study, permanent markers on the cliff top can be used to evaluate cliff recession. Cliff position relative to these markers should be recorded on an annual basis.

11.2.9 *Visual Observation*

Visual inspection of the Bay will help to identify any risk areas such as zones of increased ground movement or accelerated cliff recession. Ideally the full length of the Bay should be walked on an annual basis, to identify areas of significant change, particularly where this may result in an increased risk of loss of property or infrastructure.

Feature	Location	Interval	Method	Cost / inputs	Spatial resolution
Beach	Cayton Bay	6 months	Topographic	£4,500 /yr + 2 man days data management	As in November 2000 baseline survey, to be undertaken in conjunction with Filey Bay.
	High Red Cliff to Filey Brigg	1 year	Visual	As part of walkover survey	
Cliffs	Cayton Bay	6 months	Visual / topographic	5 man days / yr	At cliff marker locations
	High Red Cliff to Filey Brigg	1 year	Visual	As part of walkover survey	
Defences	Tenants Cliff, beach access at Killerby	1 year	Visual / topographic	2 man days/yr	
Bathymetric survey	Cayton Bay	5 years		£1,000 every 5 years + 2 man days data management	Repeat of November 2000 survey, to be undertaken in conjunction with Filey Bay.
Walkover survey	Knipe Point to Filey Brigg	1 year	Visual	4 man days /yr	
Aerial photography	Knipe Point to Filey Brigg	1 year		£25,000 for all of SMP frontage (Subject to conclusions of study by Posford Duvivier)	Scale 1:4,000
Wave recorder	These items are lower priority and are subject to being identified as providing benefit to adjacent strategies.			£40,000 /year*	
Wind records				£5,000 set-up + £1,000 /year*	
Water level gauge				£40,000 set-up + £1,000 /year*	

Table 11.2 Monitoring recommendations

** From SMP*

11.3 Further Studies

11.3.1 *Study of Hydrodynamics of Cayton Bay*

Studies of sediment processes have highlighted that limited information is available to develop a full understanding of inputs and losses to Cayton Bay from offshore and therefore the dependence of the Bay on sediment inputs from the eroding cliffs and the likelihood of increased erosion during the strategy lifetime. While it is believed that there is no shortage of sediment within the Bay, there are clear benefits in developing an understanding of these processes more fully, particularly with regard to the impact of potential dredging activities offshore of the Bay.

A full hydrodynamic model has been proposed for Filey Bay as part of the Filey Bay Strategy Study. There would be benefits in extending this model to cover Cayton Bay. This model would be developed using available information on seabed sediments, together with monitoring data that was available from the recommended monitoring campaign.

11.3.2 *Extension of strategy*

It is recommended that the strategy be extended to fill the gap between the southern limit of Cayton Bay and Filey Brigg. This will allow the impacts of cliff recession to be assessed and recommendations for future management to be made that are consistent with the adjacent strategies. It will also allow any links between the areas to be established, and will benefit from the hydrodynamic modelling recommended above.

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